(2)

REPORT OF

JOINT BOARD OF ENGINEERS

ON

ST. LAWRENCE WATERWAY PROJECT

DATED NOVEMBER 16, 1926

OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1927

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THE GREAT LAKES
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To accompany Report of Joint Board of Engineers dated November 16, 1926
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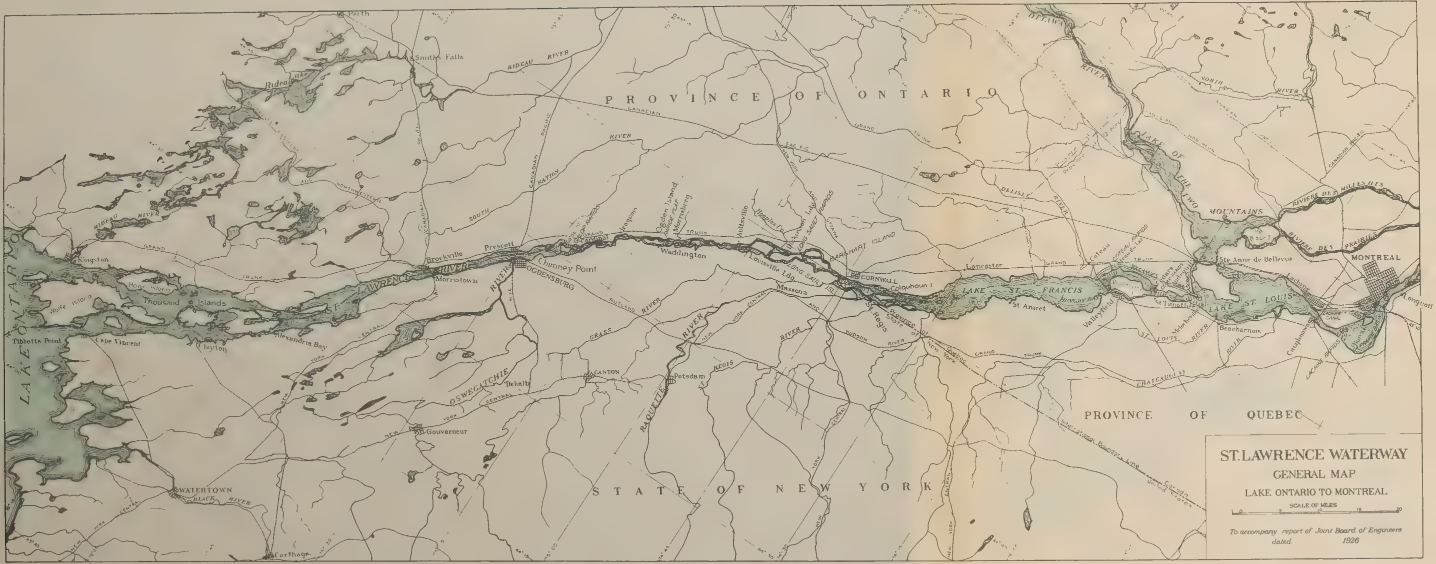
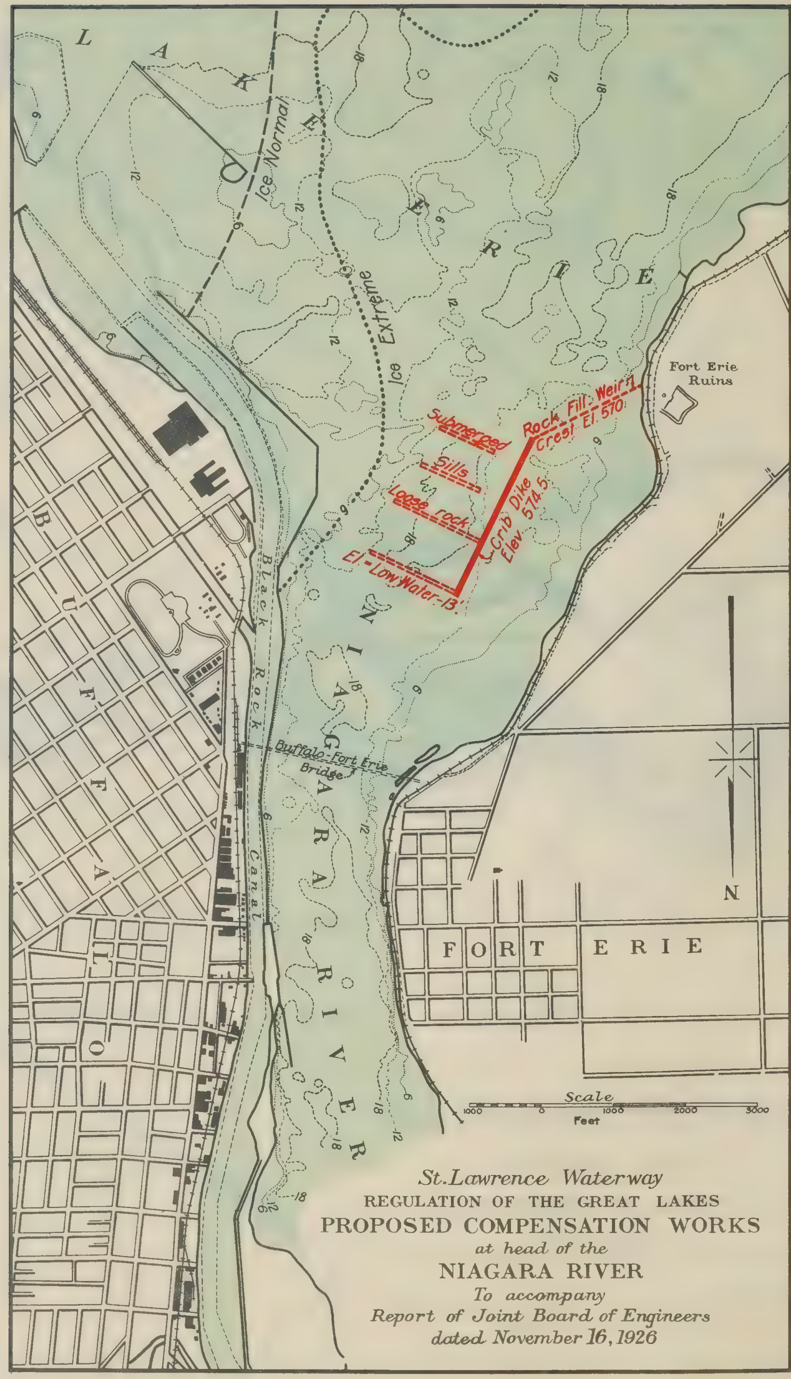
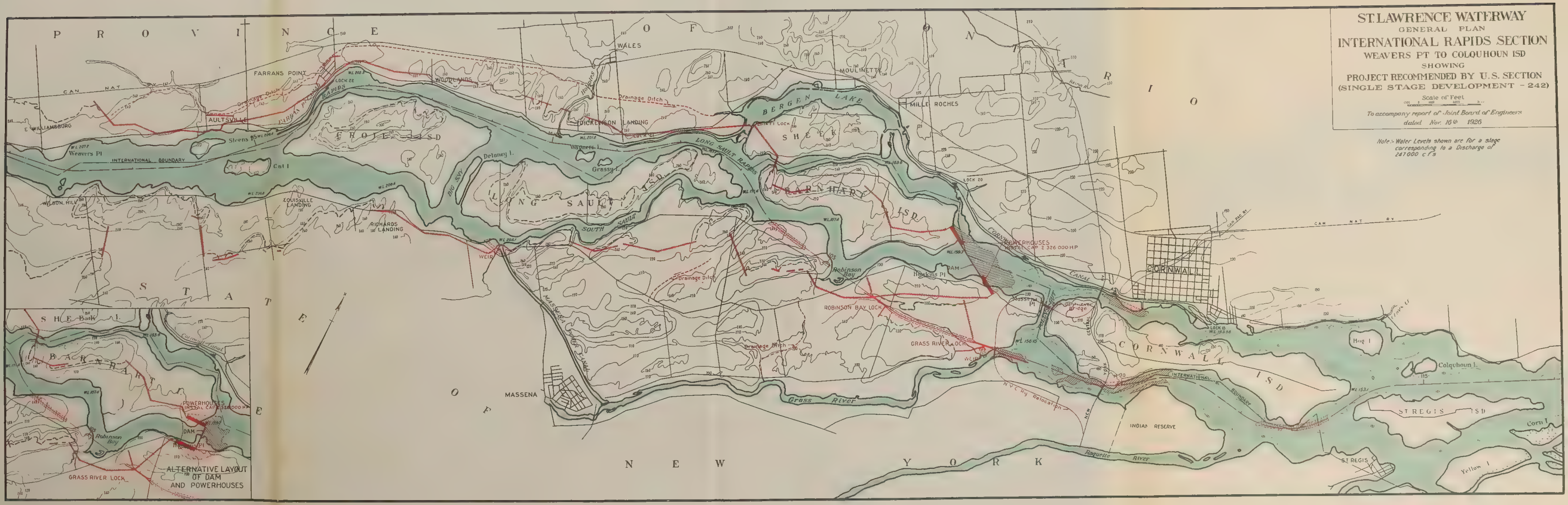
LAKE HURON
GEORGIAN BAY
LAKE ERIE
LAKE ONTARIO
LAKE SIMCOE
LAKE ST CLAIR
INTERNATIONAL BOUNDARY
PORT ARTHUR
FORT WILLIAM
DULUTH
SUPERIOR
MINN.
WISCONSIN
MICHIGAN
ONTARIO
ILLINOIS
INDIANA
OHIO
PENNSYLVANIA
NEW YORK
N.J.
MILWAUKEE
CHICAGO
SAGINAW
DETROIT
TOLEDO
CLEVELAND
ERIE
BUFFALO
TORONTO
KINGSTON
OTTAWA
MONTREAL
ALBANY
NEW YORK
St Marys River
St Marys Falls
Port Huron Rapids
St Clair River
Detroit River
Welland Canal
Niagara River
Niagara Falls
ROCHESTER
Erie Canal
Oswego Canal
Ottawa River
St Lawrence
Richelieu River
Hudson River

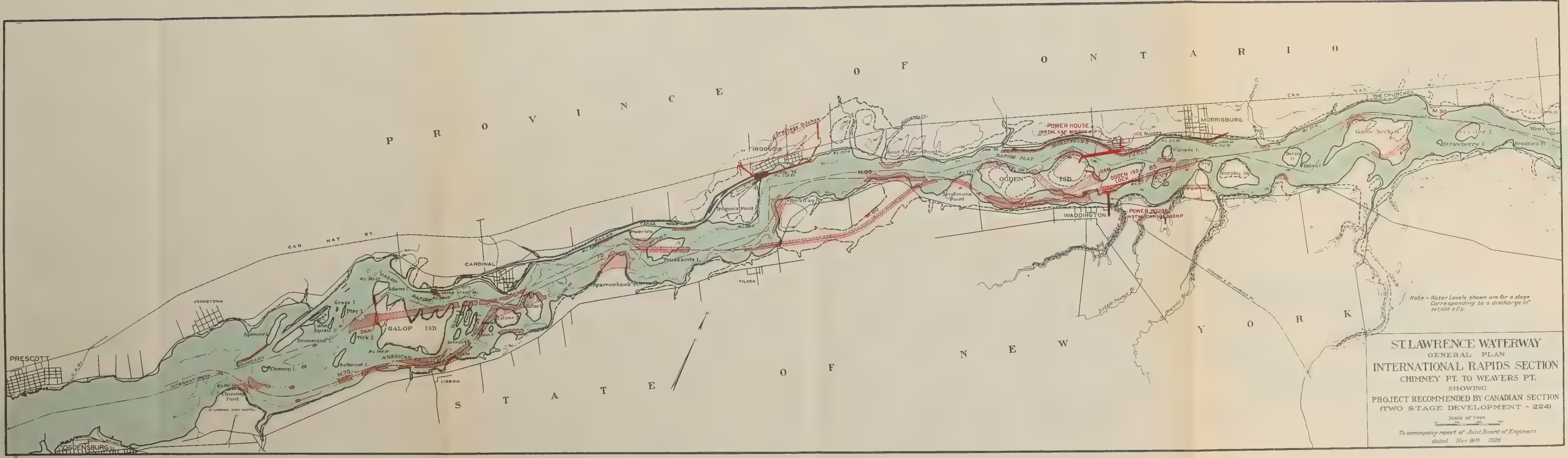

ST. LAWRENCE WATERWAY
GENERAL MAP
LAKE ONTARIO TO MONTREAL
SCALE OF MILES
To accompany report of Joint Board of Engineers dated 1926
PROVINCE OF ONTARIO
PROVINCE OF QUEBEC
STATE OF NEW YORK
LAKE ONTARIO
Perth
Smiths Falls
RIDEAU RIVER
Rideau Lake
Kingston
Wolfe Island
Howe Island
Thousand Islands
Tibbetts Point
Cape Vincent
Clayton
Alexandria Bay
ST. LAWRENCE RIVER
Brockville
Morristown
Prescott
Chimney Point
OGDENSBURG
Cardinal
Iroquois
Ogden Island
Morrisburg
Waddington
Louisville Ldg.
Massena
LONG SAULT RAPIDS
BARNHART ISLAND
CORNWALL
Colquhoun I
St. Regis
LAKE ST. FRANCIS
St Anicet
Lancaster
Coteau
COTEAU RAPIDS
Valleyfield
St Timothee
LAKE ST. LOUIS
Beauharnois
Caughnawaga
LACHINE RAPIDS
Lachine
Ste Anne de Bellevue
MONTREAL
Longueuil
LAKE OF THE TWO MOUNTAINS
OTTAWA RIVER
RIVIERE DES MILLES ILES
RIVIERE DES PRAIRIES
NORTH RIVER
DELISLE RIVER
SOUTH NATION RIVER
CANADIAN PACIFIC
GRAND TRUNK
CANADIAN NATIONAL
NEW YORK CENTRAL
RUTLAND
OSWEGATCHIE RIVER
Dekalb
GRASS RIVER
CANTON
RAQUETTE RIVER
Potsdam
ST REGIS RIVER
Gouverneur
WATERTOWN
BLACK RIVER
Carthage
CHATEAUGAY RIVER
International Boundary Line
Canada
United States

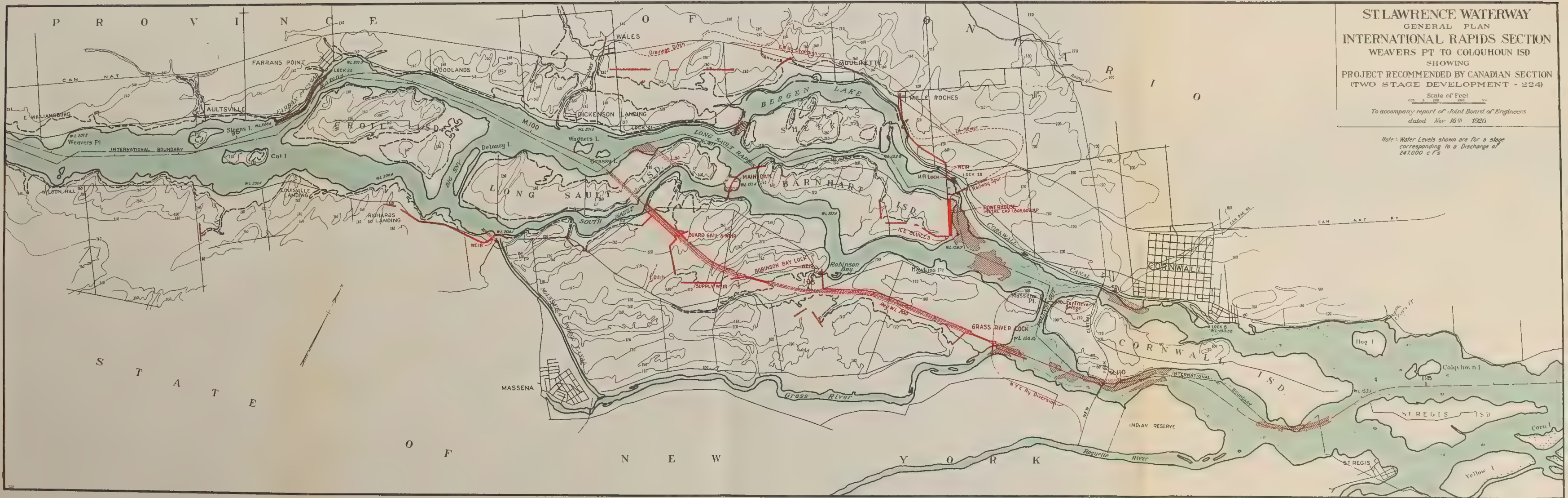


St. Lawrence Waterway
REGULATION OF THE GREAT LAKES
PROPOSED COMPENSATION WORKS
at head of the
NIAGARA RIVER
To accompany
Report of Joint Board of Engineers
dated November 16, 1926

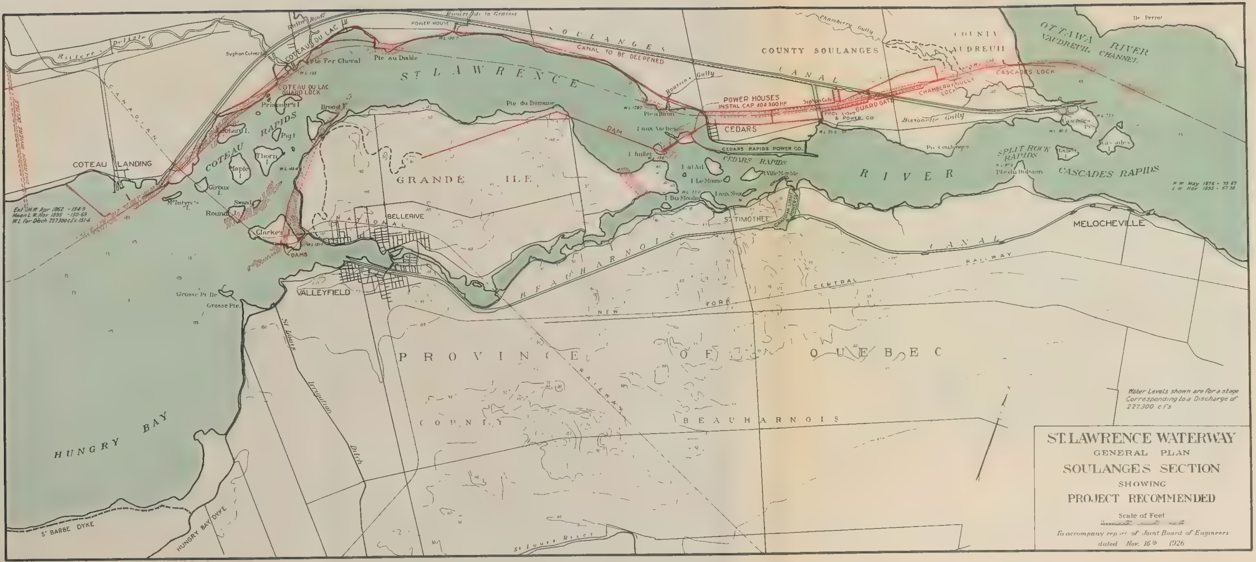

PROVINCE OF ONTARIO
STATE OF NEW YORK
PRESCOTT
JOHNSTOWN
CARDINAL
IROQUOIS
MORRISBURG
WADDINGTON
LISBON
OGDENSBURG
CAN. NAT. RY.
Drainage Ditches
Spencer I.
Drummond I.
Chimney I.
Chimney Point
Grass I.
Pier I.
Adams I.
Lame Squaw I.
Tick I.
Butternut I.
GALOP ISD
AMERICAN GALOP RAPIDS
GALOP RAPIDS
Lalone I.
Lotus I.
Sparrowhawk Pt.
Toussaints I.
Iroquois Point
Rockway Pt.
Point Three Points
RAPIDE PLAT
Leishmans Point
OGDEN ISD
Canada I.
Murphy Is.
Goose Neck I.
Crysler I.
Strawberry I.
Bradford Pt.
Weavers Pt.
Doran Is.
Indian I.
THE CHURCHES
INTERNATIONAL BOUNDARY
Note:- Water Levels shown are for a stage Corresponding to a discharge of 247,000 c.f.s.
ST. LAWRENCE WATERWAY
GENERAL PLAN
INTERNATIONAL RAPIDS SECTION
CHIMNEY PT. TO WEAVERS PT.
SHOWING
PROJECT RECOMMENDED BY U.S. SECTION
(SINGLE STAGE DEVELOPMENT - 242)
Scale of Feet
To accompany report of Joint Board of Engineers
dated Nov 16th 1926

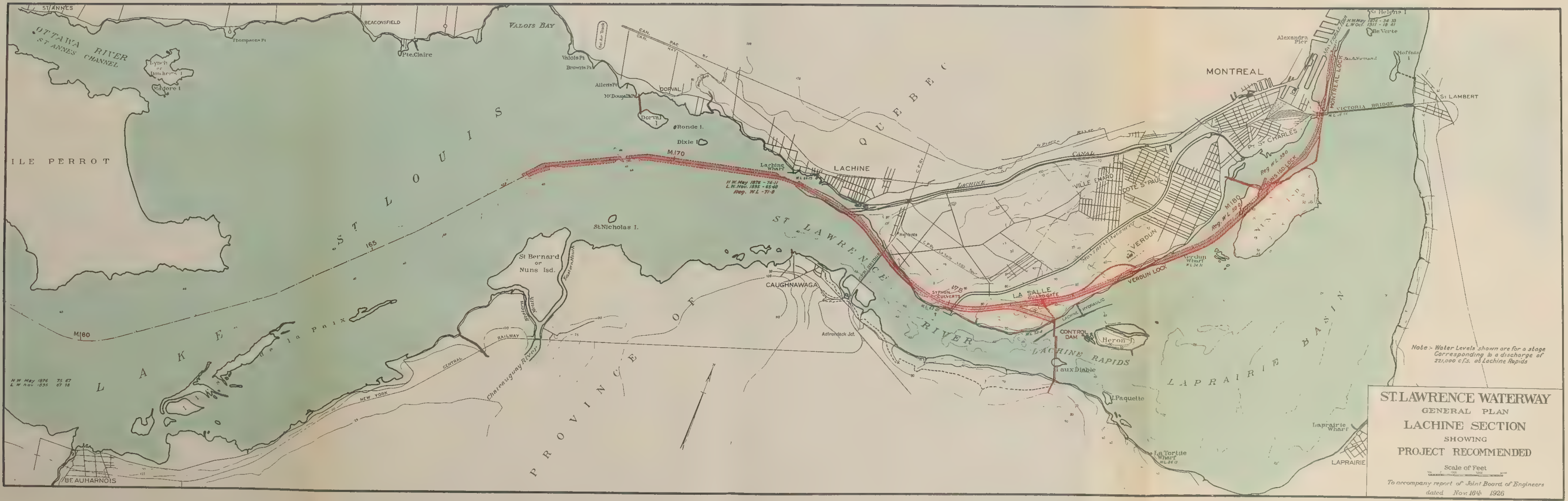

ST. LAWRENCE WATERWAY
GENERAL PLAN
INTERNATIONAL RAPIDS SECTION
WEAVERS PT TO COLQUHOUN ISD
SHOWING
PROJECT RECOMMENDED BY U.S. SECTION
(SINGLE STAGE DEVELOPMENT - 242)
Scale of Feet
To accompany report of Joint Board of Engineers
dated Nov. 16th 1926
Note - Water Levels shown are for a stage corresponding to a Discharge of 247000 c f s
PROVINCE OF ONTARIO
STATE OF NEW YORK
FARRANS POINT
WALES
WOODLANDS
MOULINETTE
MILLE ROCHES
AULTSVILLE
DICKENSON LANDING
E WILLIAMSBURG
Weavers Pt
INTERNATIONAL BOUNDARY
CROIL ISD
LONG SAULT ISD
BERGEN LAKE
SHEEK ISD
BARNHART ISD
LONG SAULT RAPIDS
FARRAN POINT RAPIDS
Drainage Ditch
Delaney I.
Grassy I.
Wilson Hill
Louisville Landing
Richards Landing
South Sault
WEIR
Robinson Bay
Hawkins Pt
DAM
POWERHOUSES
CORNWALL
CANAL
ROBINSON BAY LOCK
GRASS RIVER LOCK
Massena Pt
CORNWALL ISD
Colquhoun I.
ST REGIS ISD
MASSENA
Grass River
INDIAN RESERVE
Raquette River
ST REGIS
Cornwall Canal
ALTERNATIVE LAYOUT OF DAM AND POWERHOUSES


ST. LAWRENCE WATERWAY
GENERAL PLAN
INTERNATIONAL RAPIDS SECTION
CHIMNEY PT. TO WEAVERS PT.
SHOWING
PROJECT RECOMMENDED BY CANADIAN SECTION
(TWO STAGE DEVELOPMENT - 224)
Scale of Feet
To accompany report of Joint Board of Engineers
dated Nov 16th 1926
Note - Water Levels shown are for a stage Corresponding to a discharge of 247,000 c.f.s.
PROVINCE OF ONTARIO
STATE OF NEW YORK
PRESCOTT
JOHNSTOWN
OGDENSBURG
CARDINAL
IROQUOIS
MORRISBURG
WADDINGTON
LISBON
TILDEN
GALOP ISD
OGDEN ISD
POWER HOUSE
ICE SLUICES
DAM
CAN NAT RY
Chimney Point
Chimney I.
Spencer I.
Drummond I.
Adams I.
Toussaints I.
Sparrowhawk Pt.
Iroquois Point
Rockway Pt.
Point Three Points
Leishmans Point
Canada I.
Murphy Is.
Goose Neck I.
Strawberry I.
Bradford Pt.
THE CHURCHES
Weavers
M.70
M.80
M.90
RAPIDE PLAT
GALOP RAPIDS
Drainage Ditches
ST. LAWRENCE STATE HOSPITAL


ST. LAWRENCE WATERWAY
GENERAL PLAN
INTERNATIONAL RAPIDS SECTION
WEAVERS PT TO COLQUHOUN ISD
SHOWING
PROJECT RECOMMENDED BY CANADIAN SECTION
(TWO STAGE DEVELOPMENT - 224)
Scale of Feet
To accompany report of Joint Board of Engineers
dated Nov 16th 1926
Note:- Water Levels shown are for a stage corresponding to a Discharge of 247,000 c f s
PROVINCE OF ONTARIO
STATE OF NEW YORK
WALES
FARRANS POINT
WOODLANDS
MOULINETTE
MILLE ROCHES
AULTSVILLE
E. WILLIAMSBURG
Weavers Pt
INTERNATIONAL BOUNDARY
Cat I.
Sheeks I.
Croil ISD.
DICKENSON LANDING
Wagners I.
Delaney I.
Grassy I.
LONG SAULT ISD.
LONG SAULT RAPIDS
SOUTH SAULT
BIG SNY
BERGEN LAKE
SHEEK ISD.
BARNHART ISD.
MAIN DAM
WILSON HILL
LOUISVILLE LANDING
RICHARDS LANDING
WEIR
GUARD GATE & WEIR
ROBINSON BAY LOCK
Robinson Bay
SUPPLY WEIR
ICE SLUICES
POWERHOUSE
14 ft Lock
LOCK 20
Railway Spur
CORNWALL CANAL
CORNWALL
Hawkins Pt
Massena Pt
GRASS RIVER LOCK
Grass River
MASSENA
MASSENA POWER CANAL
NYC Ry Diversion
INDIAN RESERVE
Raquette River
CORNWALL ISD.
Hog I.
Colquhoun I.
ST REGIS ISD.
ST REGIS
Yellow I.
Corn I.
CAN NAT RY

ST. LAWRENCE WATERWAY
GENERAL PLAN
LAKE ST. FRANCIS SECTION
SHOWING
PROJECT RECOMMENDED
Scale of Feet
To accompany report of Joint Board of Engineers dated Nov. 16th 1926
LAKE ST. FRANCIS
PROVINCE OF ONTARIO
PROVINCE OF QUEBEC
ST. LAWRENCE RIVER
HUNGRY BAY
LANCASTER BAR
LANCASTER
SOUTH LANCASTER
BAINSVILLE
SUMMERSTOWN
COTEAU LANDING
St. ANICET
PORT LEWIS
St. BARBE DYKE
HUNGRY BAY DYKE
QUEBEC
NEW YORK
CANADA
UNITED STATES


ST. LAWRENCE WATERWAY
GENERAL PLAN
SOULANGES SECTION
SHOWING
PROJECT RECOMMENDED
Scale of Feet
To accompany report of Joint Board of Engineers dated Nov. 16th 1926
Water Levels shown are for a stage Corresponding to a Discharge of 227,300 c.f.s.
ST. LAWRENCE
RIVER
OTTAWA RIVER
VAUDREUIL CHANNEL
COUNTY SOULANGES
COUNTY VAUDREUIL
SOULANGES CANAL TO BE DEEPENED
CASCADES LOCK
CHAMBERRY GULLY LOCK
GUARD GATE
POWER HOUSES
INSTAL CAP 404 300 HP
CEDARS
CEDARS RAPIDS POWER CO.
CEDARS RAPIDS
SPLIT ROCK RAPIDS
CASCADES RAPIDS
COTEAU DU LAC
COTEAU DU LAC GUARD LOCK
COTEAU RAPIDS
COTEAU LANDING
GRANDE ILE
BELLERIVE
VALLEYFIELD
ST. TIMOTHEE
MELOCHEVILLE
BEAUHARNOIS CANAL
PROVINCE OF QUEBEC
COUNTY BEAUHARNOIS
HUNGRY BAY
HUNGRY BAY DYKE
St. BARBE DYKE
DAMS
DAM
NEW YORK CENTRAL RAILWAY
CANADIAN NATIONAL
Irrigation Ditch
Pte du Domaine
Pte au Diable
Pte Fer Cheval
Prisoner's I.
Pig I.
Thorn I.
Maple I.
Giroux I.
Round
Clarke's I.
Grosse Pte.
Ile Perrot
Chamberry Gully
Bissonette Gully
Roussin's Gully
Riviere Rouge
Riviere Delisle
Ext. H.W. Apr. 1862 - 156.9
Mean L.W. Nov. 1895 - 150.63
W.L. for Disch. 227,300 c.f.s. 151.6
H.W. May 1876 - 75.67
L.W. Nov. 1895 - 67.38


ST. LAWRENCE WATERWAY
GENERAL PLAN
LACHINE SECTION
SHOWING
PROJECT RECOMMENDED
Scale of Feet
To accompany report of Joint Board of Engineers dated Nov. 16th 1926
Note:- Water Levels shown are for a stage Corresponding to a discharge of 221,000 c/s. at Lachine Rapids
MONTREAL
ST. ANNES
OTTAWA RIVER
ST. ANNES CHANNEL
BEACONSFIELD
Pte. Claire
VALOIS BAY
Valois Pt.
DORVAL
Dorval I.
Ronde I.
Dixie I.
ILE PERROT
LAKE ST. LOUIS
QUEBEC
LACHINE
Lachine Wharf
LACHINE CANAL
VILLE EMARD
COTE ST. PAUL
VERDUN
LA SALLE
GUARD GATE
VERDUN LOCK
MONTREAL LOCK
VICTORIA BRIDGE
ST. LAMBERT
Pt. St. CHARLES
Alexandra Pier
St. Helens I.
Ile Verte
St. Nicholas I.
St. Bernard or Nuns Isd.
CAUGHNAWAGA
ST. LAWRENCE RIVER
LACHINE RAPIDS
CONTROL DAM
Heron I.
LAPRAIRIE BASIN
LAPRAIRIE
Laprairie Wharf
La Tortue Wharf
I. Paquette
PROVINCE OF QUEBEC
Chateauguay River
NEW YORK CENTRAL RAILWAY
Adirondack Jct.
BEAUHARNOIS
M.160
M.170
M.180
165
Verdun Wharf
SYPHON CULVERTS
LACHINE HYDRAULIC

REPORT OF JOINT BOARD OF ENGINEERS

ON

ST. LAWRENCE WATERWAY PROJECT

1. The Joint Board of Engineers appointed by the Governments of the United States and Canada presents herein its report on the improvement of the St. Lawrence River between Lake Ontario and Montreal, and on related questions referred to it by the two countries.

2. The report is subdivided into the following parts:—

Part I—Constitution of Board; Instructions to Board; General Description of Great Lakes and St. Lawrence; Prior Reports; Work Done by Board.

Part II—The Great Lakes; Existing Diversions and their Effects; Remedial Measures; The Cost of Improving the Lake Channels to conform to the Improvement of the St. Lawrence.

Part III—Improvement of the St. Lawrence above Montreal; The Plans Recommended by the Board for Improvement for Navigation and Power.

Part IV—The St. Lawrence at and below Montreal; Effect of Diversions; Remedial Measures; Effect of the Proposed Improvement of the Upper St. Lawrence on the Lower River.

Part V—Specific Answers to Questions contained in the Instructions to the Board.

PART I

CONSTITUTION OF THE BOARD

3. The President of the United States appointed, on March 14, 1924, a national committee of nine members, designated as the St. Lawrence Commission of the United States, having as its chairman the Hon. Herbert Hoover, Secretary of Commerce, to act as an advisory committee to the Government on all questions that might arise in the consideration of the project for the improvement of the St. Lawrence.

4. The Government of Canada on May 7, 1924, appointed a National Advisory Committee of nine members, having as its chairman the Hon. George Perry Graham, Minister of Railways and Canals, to advise that Government on the matters relating to the project.

5. Following a recommendation of the International Joint Commission in a Report on the Improvement of the St. Lawrence River, dated December 19, 1921, it was agreed by the two countries that a Joint Board of Engineers, consisting of three members representing Canada and three members representing the United States, should be constituted to review the plans then formulated and to report on additional related matters referred to it with the mutual approval of the two countries.

6. The United States Government designated as members of the United States Section of the Board and as advisers to the St. Lawrence Commission of the United States, the following officers, assigned to that duty by orders of the War Department, dated April 2, 1924:—

Major General Edgar Jadwin, Chief of Engineers (then Colonel, Corps of Engineers).

Colonel William Kelly, Corps of Engineers.

Lieut.-Col. George B. Pillsbury, Corps of Engineers.

7. The Government of Canada appointed on recommendation of the Privy Council, approved by the Governor General, May 7, 1924, the following members of the Canadian Section of the Board, who also act as advisers of the National Advisory Committee of Canada:—

Mr. Duncan W. McLachlan, of the Department of Railways and Canals, Ottawa.

Mr. Olivier O. Lefebvre, Chief Engineer Quebec Streams Commission, of Montreal.

Brig.-General Charles Hamilton Mitchell, C.B., C.M.G., of Toronto.

8. Instructions to Board. The instructions to the Joint Board of Engineers were agreed to by the two Governments by an exchange of notes dated February 4 and March 17, 1925, and are as follows:—

The Governments of Canada and the United States have accepted the recommendation, made by the International Joint Commission in its report dated December 19, 1921, that the question of the development of the St. Lawrence river for navigation and for the supply of power be referred to an enlarged joint board of engineers.

It is desired that the new board should review the report dated June 24, 1921, made by the late Mr. W. A. Bowden and Col. W. P. Wooten, and that it should extend its inquiries to certain additional matters with a view to supplying the technical information

likely to be relevant to the proposals made in the report of the International Joint Commission above referred to. The new board is therefore charged at this time with reporting upon the following:—

1. Is the scheme for the improvement of the St. Lawrence waterway, presented by the board in its report of June 24, 1921, practicable and does it provide to the best advantage, at this time and ultimately, for the development of the capacities and possibilities of the waterway?

2. What alternative scheme, if any, would be better adapted to secure the ends desired, due consideration being given,—

(*a*) To any special international or local interests having an importance justifying exceptional consideration; and

(*b*) To the extent and character of the damage through flooding and the probable effect of the works upon the formation of ice and the consequent effect on the flow of the river?

3. Should the estimates of cost be revised and, if so, what are the revised estimates of cost having regard to alternative schemes?

4. In order to assist either Government to allocate the amounts chargeable to navigation and power, what would be the respective estimated costs for improving the river for navigation alone and for power alone?

5. To what extent may water levels in the St. Lawrence river at and below Montreal, as well as the river and lake levels generally, be affected by the execution of the project?

6. (*a*) To what extent and in what manner are the natural water levels in the St. Lawrence river and on the lakes affected by diversions authorized by license by either Canada or the United States, from or in the St. Lawrence river watershed?

(*b*) By what measures could the water levels or navigable depths affected by the diversions referred to in section 6 (*a*) be restored, and what would be the cost thereof?

(*c*) How much power could be developed on the St. Lawrence river with the water diverted from the watershed referred to in section 6 (*a*) under—

(1) The plans recommended.

(2) Alternative plans providing for a full practical development of the river?

(*d*) Without considering compensation by the present relative diversions of water from the Niagara river and from lake Erie, and without prejudice to a future consideration thereof, what works, if any, could be constructed to recover on the St. Lawrence river the amount of power determined under section 6 (*c*), and what would be the cost of such works?

7. Having regard to economy of construction and maintenance, expedition of construction and efficiency of operation,—

(*a*) Which of the works should be constructed under the technical supervision of an international board and what other works, if any, might advantageously be constructed under such supervision?

(*b*) Which of the works should be maintained and operated by an international board and what other works, if any, might advantageously be so maintained and operated?

8. What, if any, readjustments in the location of the international boundary are necessary or desirable to place power structures belonging to either country within its borders, as recommended by the International Joint Commission?

9. If the board is of the opinion that it would be advantageous to provide in the first instance for channel depths other than 25 feet, but less than 30 feet, for what draft of vessel should provision be made?

10. Having regard to the recommendation of the International Joint Commission that the new Welland ship canal should be embodied in the scheme and should be treated as a part thereof, and to the fact that if a greater depth than 21 feet be adopted for the initial project depth of the St. Lawrence, such greater depth would not be available to the upper lake ports without further work in the navigation channels in the lakes, what would be the cost of improving the main navigation channels between and through the lakes, so as to provide, without impairing the present lake levels for (*a*) a depth of 25 feet and (*b*) for such other depth not exceeding 30 feet, as may be determined by the board to be that for which it would be most advantageous to provide on the St. Lawrence river?

11. What is the time required to complete the proposed works, the order in which they should be proceeded with, and the progress which should be made yearly toward the completion of each in order to secure the greatest advantage from each of the works and from the development of the waterway as a whole?

It is desired that the report be accompanied by such drawings as are necessary for showing the location and general character of the works proposed.

It is also desired that in the preparation of the report, due regard should be had to any diversions from or in the St. Lawrence River watershed which, at the date of the report, are authorized by license by either Canada or the United States.

It is desired that the board report, from time to time, on the matters referred to it as the progress of its inquiries permits, and that these inquiries be so prosecuted that, if practicable, the board should have reported on all such matters by the end of April, 1926.

9. Funds for the work of the Canadian Section of the Joint Board were voted by the House of Commons of Canada yearly as required. Funds for the American Section were provided by the Deficiency Act of March 4, 1925, which made available for that purpose, under the direction of the President, not exceeding $275,000 of funds appropriated for maintenance and improvement of river and harbour works.

DESCRIPTION

10. The Great Lakes are the source of the St. Lawrence, and form with it a waterway system extending from the interior of the continent to the sea. Lake Superior, the uppermost and largest of the Great Lakes, discharges into lake Huron through the rapids of St. Marys falls and the St. Marys river. Lake Michigan is connected with lake Huron by the wide and deep straits of Mackinac. Lake Huron discharges into lake Erie through the St. Clair river, lake St. Clair, and the Detroit river. Lake Erie discharges into lake Ontario through the Niagara river. From lake Ontario, the St. Lawrence flows 533 miles northeast to Father Point, which marks its transition into the gulf of St. Lawrence. The first 115 miles of the river is on the international boundary between Canada and the United States; the remainder of its course is through Canadian territory. The city of Montreal is 183 miles downstream from lake Ontario.

11. The distances by the ordinary vessel routes from Duluth, Minn., and Port Arthur, Ont., at the head of lake Superior, to Kingston, Ont., at the head of the St. Lawrence, are respectively 1,160 and 1,038 statute miles. The distance from Chicago to the head of the St. Lawrence is 1,067 miles.

12. The fall, at mean stages, between lake Superior and lake Huron is 21 feet. Lake Michigan and lake Huron are at the same level. The fall from lake Huron to lake Erie averages 8.5 feet, taken up in the slopes of the connecting rivers. The fall from lake Erie to lake Ontario is 326 feet, of which approximately 165 feet is concentrated in the drop at Niagara falls proper. The fall from lake Ontario to Montreal harbour averages approximately 226 feet, and from Montreal to the sea about 20 feet, the latter distributed through the 160 miles of river between Montreal and Quebec.

13. Present Navigation. Navigation from lake Superior to lake Huron passes through the locks at St. Marys falls. Channels have been excavated through the St. Marys river above and below the locks, and through the St. Clair river, lake St. Clair, and the Detroit river, to afford a minimum depth of 20 feet at the lake levels that have been adopted as the standard for improvements. The extreme low stages reached by the lakes during the last few years have been generally below these levels, with the result that the channel depths are less than 20 feet. In the latter part of the navigation season of 1925, the depth available was 18 feet, and at no time during that year did the maximum draft that could be carried from lake Superior to lake Erie exceed 19 feet.

14. The dredged channels between lake Superior and lake Erie aggregate nearly 100 miles in length. Their cost, for capital account only, including the costs of the locks in the St. Marys river, has been as follows:—

Expended by the United States (to June 30, 1926)	44,721,319 69
Expended by Canada (to March 31, 1925)	5,560,009 00
Total	$50,281,328 69

15. Navigation from lake Erie to lake Ontario passes through the Welland canal, constructed and operated by the Dominion of Canada. The present Welland canal affords a depth of 14 feet at normal lake levels. The new Welland ship canal, under construction by Canada, is 25 miles in length, with 7 locks each having a lift of 46½ feet, and one guard lock. The portions of this canal first excavated were given a depth of 25 feet; the later contracts provide for a depth of 27 feet. The depth over the sills of the locks is 30 feet, to provide for subsequent enlargement of the canal reaches. The cost of the new Welland ship canal to March 31, 1925, has been $50,772,092.77, and the estimated total cost when completed is $114,526,484. These figures do not include interest during construction.

16. Navigation on the St. Lawrence river from lake Ontario to Montreal is provided by isolated channel improvements and a series of side canals around the rapids (also constructed and operated by Canada), which afford 14 feet depth.

17. The channels between Montreal and the sea have been dredged to a depth of 30 feet and a project to provide a 35-foot depth is about half completed.

18. Navigation on the Great Lakes and the St. Lawrence at the present time falls into three categories:—

(*a*) Lake navigation, operating normally on 20-foot draft, on and between all of the lakes except Ontario.

(*b*) Canal navigation, operating normally on 14-foot draft, between lake Erie ports and Montreal through the Welland canal, lake Ontario, and the St. Lawrence.

(*c*) Deep-sea navigation, from Montreal to the ocean.

19. The completion of the new Welland ship canal will open lake Ontario to lake navigation, which will then be separated from deep-sea navigation by the 183 miles of the St. Lawrence above Montreal.

20. The present lake commerce is upward of 100,000,000 tons per annum. The bulk cargoes, principally iron ore, coal, and grain, are moved in a special class of vessels developed for that purpose, of great length in proportion to their draft, so designed that they can be loaded and unloaded rapidly by special machinery installed for that purpose at terminal ports.

21. The present canal commerce through the Welland and St. Lawrence canals is carried by smaller vessels of similar design. These vessels are relatively high powered, to meet the swifter currents on the St. Lawrence. This commerce has been increasing rapidly in recent years; that on the St. Lawrence canals amounted to 6,206,988 tons in 1925. Nearly all of the grain reaching Montreal harbour in recent years is transported by this route.

22. Navigation Seasons. The average dates of opening and closing navigation on the inter-connecting channels of the Great Lakes and on the St. Lawrence river during the last twenty years have been as follows:—

Great Lakes above Welland canal, April 18 to December 19.
Welland canal, April 18 to December 16.
St. Lawrence canals above Montreal, April 26 to December 9.

The average date of the arrival of the first vessel from the sea into the port of Montreal during the last ten years has been April 28; the average date of the last departure for the sea, December 7.

23. The St. Lawrence. The part of the St. Lawrence with which this report is particularly concerned lies between lake Ontario and Montreal. The river here runs in deep slow-flowing reaches and lake-like expansions, readily improved for navigation, with intervening reaches of rapids and swift currents. For the first 67 miles from lake Ontario the river is a deep slow-flowing stream. It then passes through the remaining 49 miles of the international border in a succession of rapids and swift water. Leaving the border, the river expands into the quiet waters of lake St. Francis. From this lake it drops in a succession of rapids to lake St. Louis, and from lake St. Louis drops through more rapids to Montreal harbour.

24. As it is fed from the great reservoirs formed by the lakes, the St. Lawrence has a remarkably steady flow. The mean discharge out of lake Ontario during the past 66 years has been 246,000 cubic feet per second, the maximum average discharge for any month 318,000 cubic feet per second, and the minimum average discharge for any month 174,200 cubic feet per second. Except where affected by ice gorging in winter, the fluctuations in the river surface nowhere exceed a few feet. The bed and banks are not subject to erosion and the river is free from silt.

25. Geologically, the St. Lawrence is a new river. Rock surfaces exposed indicate the passage of the continental glaciers across the valley, and the bed of the swifter portions is paved with boulders from them, mingled with those formed from the country rock. The rock itself, as determined by borings, is generally uniform in contour, but is broken by valleys and ridges which strike across it northwards. These are sometimes intersected by depressions from pre-glacial drainage. In the upper reaches the rock disclosed by borings is crystalline limestone of a firm character and close texture, mostly quite suitable for supporting hydraulic structures. Between lakes St. Francis and St. Louis rock is a hard limestone and a hard sandstone, equally sound. In the lower reaches around Lachine and Montreal, there are igneous intrusions amongst limestone and shale which, while providing firm foundations, would require special protection against scouring.

26. The main banks and islands of the river are formed of mixtures of clay, sand, gravel, and boulders, lying or deposited on the rocky floor of the valley. These materials are mixed in strata and irregular bodies but, in general, tight enough to form fairly watertight foundations for hydraulic structures under low heads. The high points on both islands and mainland are capped with extensive but shallow boulder deposits.

PRIOR REPORTS

27. On the 21st of January, 1920, the Governments of the United States and Canada referred to the International Joint Commission, created by the treaty of the 11th of January, 1909, between the Governments of the United States and Great Britain, questions relating to the improvement of the St. Lawrence river between lake Ontario and Montreal for the purpose of making it navigable for deep-draft vessels, and securing the greatest beneficial use of the water for power.

28. Each of the Governments also designated an engineer to co-operate in the surveys necessary to plans for improvement, and in the preparation of plans and estimates. These engineers were instructed to submit the surveys, plans and estimates to the International Joint Commission.

29. Colonel William P. Wooten, Corps of Engineers, United States Army, was designated as the engineer for the United States, and the late Mr. W. A. Bowden, Chief Engineer, Department of Railways and Canals, was designated as the engineer for Canada, these officers receiving identical instructions from their respective Governments.

30. Report of 1921. Their report was submitted to the International Joint Commission on June 24, 1921. It is hereinafter referred to in this report as the Report of 1921. The salient conclusions and recommendations in that report are as follows:—

(1) That the physical conditions (on the St. Lawrence) are favourable for improvements for navigation which will be permanent, and will have very low upkeep costs.

(2) That improvement of the entire reach from Montreal to lake Ontario for navigation alone is feasible, but the loss of the power that can be generated as a by-product in some reaches is not warranted.

(3) That the development of nearly all the potential power in the river, amounting to approximately 4,100,000 horse-power, can be made as co-ordinate parts of schemes for the improvement of navigation.

(4) That the simultaneous development of such a vast quantity of power is not a sound economic procedure, as a market to take this output is not now in existence, and cannot be expected to spring into being at once.

(5) That the sound method of procedure is to improve for navigation along those reaches where side canals and locks can most economically be used, and where the development of the power at some future time is not interfered with by the proposed improvements; and in that part of the river where the construction of locks and dams offers the most feasible means of improving navigation to provide for the development of the incidental power obtainable as a result of the heads created by the dams.

(6) That the improvements undertaken afford a navigation channel 25 feet in depth, with lock sills 30 feet in depth, so built as to permit the eventual enlargement of the channel to that depth.

(7) That the improvement be secured by the combined development for navigation and for power of the rapids section on the international boundary, side canals around the other rapid sections, and the necessary channel excavation elsewhere.

31. The estimated cost of the entire work to provide a 25-foot channel and to develop 1,464,000 horse-power was as follows:—

First division—side canal from Montreal Harbour to deep water in lake St. Louis	55,783,000
Second division—side canal from deep water in lake St. Louis to deep water in lake St. Francis	36,590,000
Third division—channel dredging in lake St. Francis	1,158,000
Fourth division—combined navigation and power development in international section, with annual power output of 1,464,000 horse-power (total installed capacity approximately 1,850,000 horse-power)	159,097,200
Fifth division—navigation improvement above rapid section	100,000
Total	$252,728,200

32. The estimated cost of increasing the navigable depth throughout the entire stretch to 30 feet at a later date was $17,986,180.

33. The report considered, but did not recommend, plans for power development in the First and Second divisions, respectively.

34. Of the total estimated cost of the project, $159,097,200 was for the combined navigation and power development on the international section of the river. A head of 74 feet was to be developed by a dam across the river at the Long Sault rapids. A second dam was to be constructed 23 miles upstream at Ogden island, just upstream from Morrisburg, to provide navigation through the upper rapids of the reach, afford control over the flow of the river and insure suitable winter operation. The head of approximately 8 feet available at this dam in summer was not to be developed. The main dam and related structures were, however, to be so designed that they could be raised subsequently so as to utilize fully whatever head the operation of the works might show to be economically practicable.

35. It was estimated that if the improvements were carried on simultaneously it would be possible to complete them in eight years from the time the work was begun, if funds were made available as fast as needed.

36. The report pointed out that the construction of the upper dam proposed (at Ogden island) and the enlargement of the discharge capacity of the upper reaches of the river would afford control over the level of lake Ontario and the flow in the St. Lawrence river. This control can be so exercised as to raise the mean level of the lake without causing it to fluctuate beyond the limits previously reached. The studies made did not show, however, that any very great increase in the natural low-water flow can be made for the benefit of either power or navigation in Montreal harbour, or the ship channel below.

37. The engineers of the two countries united in all of the recommendations contained in the Report of 1921, except as to the program of regulation of the levels and outflow from lake Ontario which should be put into effect after the project was completed, each submitting a program regarded as most suitable to that end. The essential difference between the two was that the program proposed by the Canadian engineer provided for a greater restriction of the winter flow, with a view to creating more desirable ice conditions. With this restriction it was not possible to secure quite as favourable results from regulation as would be afforded by the program proposed by the United States engineer.

38. The plans presented in the Report of 1921 were made the subject of public hearings before the International Joint Commission. At these hearings

several alternative plans were presented for the consideration of the commission, especially with relation to the development of power in the International Section.

39. Recommendations of International Joint Commission. The report of the International Joint Commission included the following recommendations:—

(1) That the Governments of the United States and Canada enter into an arrangement by way of treaty for a scheme of improvement of the St. Lawrence river between Montreal and lake Ontario.

(2) That the new Welland ship canal be embodied in said scheme and treated as a part thereof.

(3) That the proposed works between Montreal and lake Ontario be based upon the report of the engineering board—(Report of 1921)—but that before any final decision is reached the report of the board, together with such comments, criticisms and alternative plans as have been filed with the commission be referred back to the board enlarged by other leading members of the engineering profession, to the end that the whole question be given that further and complete study that its magnitude and importance demand, and that after completion the administrative features of the improvement be carried out as set forth in recommendations 7 and 8 hereof.

(4) That there shall be an exhaustive investigation of the extent and character of the damage through flowage involved in the plan of development finally adopted.

(5) That, assuming the adoption of the plans of the engineering board, or of other plans also involving a readjustment of the international boundary, in order to bring each of the power houses on its own side of the boundary, appropriate steps be taken to transfer to one country or the other, as the case may be, the slight acreage of submerged land involved.

(6) That Canada proceed with the works necessary for the completion of said new Welland ship canal in accordance with the plans already decided upon by that country.

(7) That such "navigation works" as do not lie wholly within one country or are not capable of economic and efficient construction, maintenance and operation within one country as complete and independent units, be maintained and operated by a board hereinafter called "the International Board," on which each country shall have equal representation.

(8) That such "navigation works" as lie wholly within one country and are capable of economic and efficient construction, maintenance and operation as complete and independent units be maintained and operated by the country in which they are located with the right of inspection by the said international board to insure economy and efficiency.

(9) That "power works" be built, installed and operated by and at the expense of the country in which they are located.

(10) That, except as set forth in recommendation (11), the cost of all "navigation works" be apportioned between the two countries on the basis of the benefits each will receive from the new waterways: Provided, That during the period ending five years after completion of the works—and to be known as the Construction Period—the ratio fixing the amount chargeable to each country shall be determined upon certain known factors, such as the developed resources and foreign and coastwise trade of each country within the territory economically tributary to the proposed waterway, and that that ratio shall be adjusted every five years thereafter and based upon the freight tonnage of each country actually using the waterway during the previous five-year period.

(11) That the cost of "navigation works" for the combined use of navigation and power over and above the cost of works necessary for navigation alone should be apportioned equally between the two countries.

WORK DONE BY THE JOINT BOARD OF ENGINEERS

40. A program of the field work and office investigations to be undertaken respectively by the two sections of the Board was adopted at a meeting held at Ottawa, April 13-16, 1925. This embraced surveys of the sections of the river not previously covered in detail, and borings to determine foundation

conditions at sites of proposed structures, with a special examination by shafts and borings at the site of the dam proposed in the Report of 1921 at the Long Sault rapids.

41. The Canadian Department of Railways and Canals, having available the data collected for the Report of 1921, continued investigations on the St. Lawrence river through the years 1922 and 1923 until the appointment of this Board in the spring of 1924. Through the remainder of that year the Canadian Section of the Board further continued these investigations, and in Aprli, 1925, after the adoption of the Board's program, both of the sections vigorously prosecuted extensive surveys and discharge meterings together with numerous borings, completing these in the summer of 1926. The United States Section devoted itself mainly to surveys and borings in the International Section, including the special work at dam sites around Long Sault rapids. The two sections together have made upwards of 400 borings covering the most critical portions of the St. Lawrence river between the Galop and Lachine rapids; these included a set of borings across the river in the swift water at the head of the Cedars rapids. The Canadian Section carried out in November and December of 1924 and 1925 an extended set of temperature measurements to determine the rate of loss of heat in the river, and in February and March, 1926, a set of experiments to determine the resistance of ice as bearing on the design of dams in the river.

42. Each section employed a competent and extensive engineering force in office and field to carry out its investigations. The office staff of the United States Section was maintained at the United States Lake Survey, Corps of Engineers, United States Army, at Detroit, and the Canadian, at the Department of Railways and Canals at Ottawa. The United States Section engaged the services of the engineering firm of Viele, Blackwell and Buck as consulting engineers on features relating to power development.

43. The Board had available for its use a large volume of data obtained from other sources. This consisted not only of topographic and hydraulic information concerning the lakes and river, but a great number of boring determinations as well as construction and price data useful for estimating purposes. The various departments of the Canadian and United States Governments contributed a large part of this. Other sources of information were the reports of the United States Board of Engineers on Deep Waterways of 1900 and the Georgian Bay Canal Survey of 1908, and data supplied by the St. Lawrence Power Company, the Canadian Light and Power Company, and the Montreal Light, Heat and Power Consolidated, and by the Hydro-Electric Power Commission of Ontario which for several years has carried on extensive investigations in the vicinity of Morrisburg and the Long Sault rapids. The Board has had a special advantage with respect to navigation cost data in the current prices established on the new Welland ship canal, a similar work now under construction. The Board has also received much valuable data from operating power companies and manufacturers of hydraulic and electrical machinery in both countries.

44. The Board held frequent meetings at various points on the river and Great Lakes, to study and discuss the problems involved in the improvement.

45. The results of these various investigations are set forth in appendices to this report.

PART II

IMPROVEMENT OF LEVELS AND OUTFLOW OF THE GREAT LAKES

46. This part of the report deals with,—

(*a*) The extent to which the levels of the Great Lakes are affected by diversions of water (Question 6*a* of the instructions to this board).

(*b*) The feasible measures for raising the levels of the lakes to correct the effect of authorized diversions, and to reduce the cost of improving the lake channels (Questions 6*b* and 10).

(*c*) The extent to which the outflow from the lakes can be improved by the manipulation of their levels (Question 6*d*).

(*d*) The cost of deepening the channels through and between the lakes (Question 10).

DESCRIPTION

47. The Great Lakes serve two great economic uses; as navigation routes of vital concern to the two countries; and as a reservoir to equalize the flow of the St. Lawrence river.

48. The supply of water to the Great Lakes is furnished by the inflow of the many relatively small rivers of their drainage basins, increased by the rainfall on the lakes themselves, and decreased by the evaporation from the lake surfaces. The total area of the drainage basins of the lakes is approximately 300,000 square miles, of which nearly one-third is occupied by lake surface. Computations show that the average supply received from the land areas about equals that received as rainfall on the lakes, but that roughly 40 per cent of this total gross supply is lost by evaporation. The net supply varies widely. The records show rates of net supply to the whole lake system exceeding 800,000 cubic feet per second for a month; and they also show months during which the evaporation from the lakes exceeded the water received from all sources, with a consequent negative net supply. The average monthly net supply for the months of April and May is at a rate exceeding 500,000 cubic feet per second; and the average net supply for the month of November is at a rate of less than 20,000 cubic feet per second.

49. Notwithstanding this wide variation in supply, the monthly mean outflow from the lakes during the past 65 years has ranged between the narrow limits of 318,000 cubic feet per second and 174,000 cubic feet per second. But even this minimum was due partly to ice retardation. The minimum monthly mean discharge with open-river conditions was 194,000 cubic feet per second.

50. The lakes absorb the great variations in supply because of the rise and fall of their levels. When the supply is high, they rise and store water; when it is low they fall and deliver the stored water. The average annual rise and fall of the various lakes due to the seasonal variations in supply is from 1¼ feet to 2 feet; but extreme variations in seasonal supply have caused fluctuations in lake levels ranging from 2.67 feet on lake Superior to over 4 feet on lake Ontario. Extreme high and low lake levels are reached at the ends of periods of excessive or deficient supply extending over several years. The maximum ranges of the montly mean levels of the various lakes since 1860 vary from 3.5 feet on lake Superior to a little more than 6 feet on lakes Michigan and Huron.

51. The period of low rainfall occurring during the past few years has brought down the levels of the lakes, and with other factors mentioned later has created record low levels on lakes Michigan, Huron and Erie. The rains of the summer of 1926 have, however, started the levels upward, and the lakes will return to their ordinary levels if the increased rainfall continues.

DIVERSIONS AND OUTLET ENLARGEMENTS AFFECTING LAKE LEVELS

52. It is evident that as the level of a lake falls, that of its outlet river will fall also, and the discharge capacity of the outlet river will be reduced. When water is diverted from the outlet, the lake levels will be steadily lowered with respect to their natural levels until the discharge capacity of the outlet has been reduced by an amount corresponding to the diversion, after which the effect of the diversion on lake levels ceases to increase. Thus, at mean stages of lake Erie, a fall of 6 inches in its level will reduce the discharge capacity of its outlet, the Niagara river, by 11,000 cubic feet per second. After a diversion of 11,000 cubic feet per second has lowered lake Erie by 6 inches, it will be balanced by the reduced outflow, and from then on the lake levels will remain substantially 6 inches below the levels that they would have if the diversion were not in existence.

53. The relation between the volume of flow of the various outlet rivers and the elevation of their water surface, or stage, has been accurately determined by repeated current-meter measurements made during the past quarter century, and the amounts by which the various existing diversions have affected the lake levels can be stated with assurance.

54. The time required for the decreasing outflow to reach an equilibrium with the decreased supply due to a diversion depends on the area of the lake in relation to its outlet capacity. Under present conditions, approximate equilibrium is reached on lakes Erie and Ontario in about a year, but several years are required to establish this equilibrium on the great reservoir formed by the combined areas of lakes Michigan and Huron.

55. It is obvious that any enlargement of the outlet channel will lower the level of a lake in the same manner as a diversion of water.

56. The levels of the Great Lakes have been affected by the following artificial factors:—

(*a*) The operation of the regulating works constructed to correct for the power diversions in the St. Marys river at the outlet of lake Superior.
(*b*) The diversion of the Chicago Sanitary District from lake Michigan.
(*c*) Diversions from lake Erie for power and navigation through the Welland canal and from the Niagara river.
(*d*) Changes in the discharge capacity of the St. Clair river at the outlet of lake Huron, and of the St. Lawrence river affecting lake Ontario.

57. Effect of Regulating Works, St. Marys River. The extensive diversions of water for power development at St. Marys falls, amounting to approximately 50,000 cubic feet per second, has made necessary the installation of gates across the river, at the head of the falls, to control the outflow and levels of lake Superior. The gates are operated and the diversions are controlled by an International Board of Control in accordance with conditions laid down by the International Joint Commission, May 26-27, 1914. Their operation substitutes artifi-

cial for natural control of the levels of lake Superior, and has, in general, increased the levels of that lake at low water, and somewhat diminished those at high water. The control of the outflow of lake Superior for power and for navigation at St. Marys falls has therefore, in general, been beneficial rather than injurious in its effect on the levels of lake Superior.

58. The operation of these regulating works has affected somewhat the levels of the other lakes, since the controlled discharge from lake Superior into them is at times greater than the natural discharge, and at times less. A computation shows that the maximum effect since the regulation was begun was reached in 1922 and 1923, when lakes Michigan and Huron were lowered by 4½ inches, and lakes Erie and Ontario by 3 inches. From 1923 to 1925 the release of water from lake Superior was in excess of the outflow that would have occurred under natural conditions, with the consequence that by January, 1926, the other lakes were slightly higher than they would have been had there been no regulation of lake Superior.

59. Diversion of Chicago Sanitary District. The diversion by the Sanitary District of Chicago of an average yearly flow of 8,500 cubic feet per second from lake Michigan through the Chicago Drainage canal into the basin of the Mississippi river has been authorized by the United States under the terms of a revokable permit issued by the Secretary of War, effective March 3, 1925. The permit was issued subject to the conditions, among others, that the Sanitary District should construct extensive sewage purification works, and control works in the river, within five years, and provides that the authorization shall terminate on December 31, 1929, unless specifically extended. The estimated cost of the sewage purification works required under the permit is $92,000,000. It is reported that these works are 46 per cent completed.

60. The diversion by the Sanitary District authorized by the permit is exclusive of the water pumped by the city of Chicago into its water-supply system and thence passing through the sewers into the Drainage canal. The amount so diverted in 1924 was reported as about 1,200 cubic feet per second. The permit was made contingent upon the adoption by the city of Chicago of an extensive program for metering its water service, and the execution of this program within ten years. The metering, which is estimated to cost $15,000,000, will reduce the amount of water diverted through the city water-supply system, and will expedite the sewage purification by reducing the volume to be treated.

61. The official reports of the War Department show that the total diversion, including that diverted via the water-supply system, has averaged 8,660 cubic feet per second during the past five years. The Secretary of War, in issuing the permit, informed the Sanitary District that the diversion of water should be reduced to reasonable limits with utmost despatch. It was appreciated that the desired reduction could not be made instantaneously, but the conditions required under the permit were drawn with a view to making a substantial reduction by the time the permit expires.

62. The diversion of the Chicago Sanitary District authorized by license by the United States is taken in the present report as the diversion of 8,500 cubic feet per second specifically authorized in the permit issued by the Secretary of War.

63. Black River Diversion. There is a small diversion from lake Huron into the Black river, which discharges into the St. Clair river below the head of the latter. Its effect on lake levels is negligible.

64. Diversions from Lake Erie. On the Welland canal, in addition to the water required for lockages, etc., diversions for power purposes aggregating the equivalent of a total of 2,050 cubic feet per second have been authorized by the Department of Railways and Canals of the Dominion of Canada. The best measurements available indicate a total present average flow of 3,100 cubic feet per second for both navigation and power. More water will be required for the large locks of the new deep-draft canal now under construction. The Board is informed by the Chief Engineer, Department of Railways and Canals of the Dominion of Canada that the total average flow will not exceed 5,000 cubic feet per second after the new canal is put in operation.

65. On the Niagara river a diversion for navigation purposes through the Black Rock canal, operated by the United States to carry lake shipping past the rapids at the head of the river, has a small effect on the levels of lake Erie. There is a diversion of approximately 1,500 cubic feet per second through the New York State Barge canal, including 275 cubic feet per second for power purposes. This water is drawn from the Niagara river at Tonawanda below the rapids at the head of the river and is discharged into lake Ontario. Its effect on lake levels is negligible. The effect of the considerable diversions for power on the Niagara river has been compensated for, at least to a large degree, by intake structures and the deposit of excavated material. The effect of the power diversions on the levels of lake Erie, if any, is also regarded as negligible.

66. The diversions via the Welland canal and the Black Rock canal affect not only the levels of lake Erie, but also to a small degree the levels of lakes Michigan and Huron.

67. Changes in St. Clair River. The St. Clair river (the outlet of lake Huron) is the one outlet of the Great Lakes system whose discharge capacity is not controlled by a natural weir of rock. The river has a sand and gravel bed. Any change in the slope of the river has an effect on the level of lake Huron. At the entrance from lake Huron it is contracted in a deep and narrow channel known as the Port Huron rapids, changes in the cross-sectional area of which have a much greater effect than those in any other similar length of the river. There is every reason to believe that this contraction was formed by the drift of beach gravel from lake Huron.

68. A detailed analysis of all available gauge records made by the United States Lake Survey indicates that between 1890 and 1900 discharge capacity of the St. Clair river increased possibly to the extent of 0.34 foot of stage of Huron. The question has been raised as to whether this was due to the dredging of navigation channels in the river. Most of such dredging was done, however, through the delta of the St. Clair, where the river flows with a flat slope through a number of channels into lake St. Clair, and the extent of the dredging was insufficient to produce any sensible increase of the discharge capacity of the river as a whole. A more probable explanation of the apparent increase in discharge capacities during that period is the natural erosion of the gravel bed of the Port Huron rapids.

The discharge measurements subsequent to 1899 afford a more definite basis for determining the changes in the discharge capacity of the river since that year. The shoaling caused by the wrecks of two schooners in the Port Huron rapids in 1900 reduced the discharge capacity by 0.1 foot of stage, leaving a net change of 0.24 foot to that date. No further change is indicated by the discharge measurements until after 1908.

69. The computations of the United States Lake Survey show that, between 1908 and 1925, the discharge capacity again enlarged to the extent of 0.38 foot of stage, and that this increase occurred in the contracted section near the head of the river. Its computations show no indication of any sensible increase in the discharge capacity except in this section. They do not show that the dredging done for the improvement of navigation during this period (embracing the removal of a shoal opposite Port Huron to the depth required for navigation), or the dredging of gravel for commercial purposes downstream from this contracted section, which has been permitted by both the United States and Canda, has sensibly affected the discharge capacity of the river.

70. In order to improve the navigable depth to the Point Edward docks, at the foot of the Port Huron rapids, the Department of Public Works of the Dominion of Canada authorized the licensees of the province of Ontario to dredge gravel in this contracted section. The records of the province show a total of 1,519,000 cubic yards dredged from this locality during the period. A survey made in 1925 disclosed that this dredging had been carried on by the licensees and others to such an extent as to create a material enlargement of the cross-sectional area of the river through a distance of about 6,000 feet, such enlargement for about one-half this distance amounting to more than 30 per cent of the original area. This survey showed an apparent removal of 2,400,000 cubic yards. The computed effect of the enlargement is 0.29 foot and agrees reasonably closely with the observed increase in the discharge capacity during the period. The survey showed that the narrow section above the location of the dredging had contracted during the period, leaving this dredging as the only assignable cause of the increase in the discharge capacity of the river.

71. From the above figures, the total effect of the enlargement of the discharge capacity of the river is taken at 0.6 foot of stage.

72. Precise information as to the effect of gravel dredging in the part of the river below Point Edward cannot be given at the writing of the report, but a joint survey is being made by the officers of the two countries covering the uppermost six miles of the river. From this survey further information will become available in regard to this matter.

73. Changes in Detroit River. The Detroit river has a wide sill of ledge rock across its lower reaches. The enlargement of the natural channels through this section of the river was commenced in 1876 and has been progressive since that time. In the lack of contemporaneous discharge measurements, the effect of the earlier excavation cannot be determined, but the amount of this excavation is insufficient to have caused any material increase in the discharge capacity of the St. Clair-Detroit outlet as a whole. In 1907 the excavation of a new straight channel, known as the Livingstone channel, was begun, but in the execution of the work the excavated material was so deposited as to compensate for the enlargement. The discharge measurements and computations made by the United States Government engineer in charge of the improvement since the opening of the channel have convinced the Board that the compensation for all channel excavation since 1901 was accomplished.

74. Changes in Niagara River. The Niagara river has had various minor contractions by bridge piers, shore encroachments, etc., and enlargements through the dredging of gravel for commercial purposes. Recent discharge measurements show that these have so closely balanced each other that the discharge capacity of the river has been substantially unchanged.

75. Changes in St. Lawrence River. In the St. Lawrence river, the works undertaken by the Canadian Government in connection with the present 14-foot navigation included the closure of a minor channel at the head of the Galop rapids by what is known as the Gut Dam. This work was undertaken for the purpose of improving navigation at the rapids, but caused a reduction in the discharge capacity of the outlet of lake Ontario, which, in addition to counteracting minor channel enlargements made in the same period, raised the levels of the lake by somewhat more than 0.4 foot.

76. Control of Dredging Sand and Gravel in Outlet Rivers. The estimates of the cost of the channels of specified depths through and between the lakes, hereinafter presented, are based on the premise that the lake levels will not be lowered by the further enlargement of their outlets through the dredging of sand and gravel for commercial purposes. The control of this dredging to prevent injurious enlargements is now being considered in correspondence between the two countries.

77. Summary of Effect of Diversions and Outlet Changes. Omitting the small and varying changes resulting from the regulation of lake Superior, the effect of the various diversions and outlet changes is found to be as follows. The minus sign indicates a lowering of lake levels and the plus sign a raising of lake levels.

Cause	Amount of diversion, cubic feet per second	Effect, in feet, on levels of Lakes		
		Michigan and Huron	Erie	Ontario
Authorized Diversions:—				
Chicago Sanitary District	8,500	−0·5	−0·4	−0·4
Power diversions, Welland canal	2,050	−0·025	−0·1	0
All present diversions and outlet changes:—				
Chicago Sanitary District	8,660	−0·5	−0·4	−0·4
Welland canal	3,100	−0·04	−0·15	0
Black Rock canal	1,000	−0·01	−0·05	0
Changes in St. Clair river outlet—				
Prior to 1908		−0·3		
Subsequent to 1908		−0·3		
Gut Dam				+0·4
Total		−1·15	*−0·6	0·0

* Upon the opening of the new Welland Ship Canal the lowering of the level of Lake Erie will be increased to 0.7 feet.

IMPROVEMENT OF LAKE LEVELS AND OUTFLOW

78. Compensating and Regulating Works. The levels of the Great Lakes can be raised by works in their outlet rivers, which may be wholly in the form of fixed weirs and contractions or may be provided with sluice gates. The first of these have come to be termed compensating works, while the second are termed regulating works.

79. The effect of compensating works is to raise both the high and low lake levels in substantially the same degree, the fluctuation of levels remaining unchanged. After the lake levels have adjusted themselves to the new regimen of the outlet, the outflow from the lake will likewise be substantially the same as

if the compensating works had not been built. By operating the gates of regulating works, the discharge from a lake, and consequently the levels of the lake, can be controlled within limits to be discussed later.

80. Regulation of Lake Ontario. The regulation of Lake Ontario is an inherent part of the plans for the improvement of the St. Lawrence river for navigation and power, proposed in Part III of this report, since these plans include a major enlargement of the rock sill at the head of the Galop rapids, which now controls the outflow from the lake, and provide for the control of outflow by sluice gates. The program for the regulation of lake Ontario recommended by the Board is presented in Appendix B.

81. Regulation of Other Lakes. Since regulating works are already in operation at the outlet to lake Superior, as a consequence of the large power diversions at St. Marys falls, there remains only the consideration of compensating or regulating works at the outlet of lake Huron (controlling also the levels of lake Michigan) and of lake Erie.

82. A widespread belief has arisen among members of the engineering profession as well as among the public at large, that a remedy for low lake levels and discharges can be found through a comprehensive system of regulation of these lakes. The Board has given the question searching study, and has turned to compensating works in the outlets of lake Huron and Erie only after it was found that the results that can be secured from regulating works are entirely incommensurate with their cost.

83. Limitations of Lake Regulation. To many of the persons concerned in the levels of the Great Lakes, the apparent remedy for such low-water levels as are now occurring is the construction of regulating works across their outlets, with gates which can be closed at low-water periods to hold back the water which now runs out in excess of the supply, and which can be opened when the supply again becomes normal. It is the excess discharge during low-water periods, however, that furnishes the bulk of the flow of the Niagara and St. Lawrence rivers. There have been times when, for two months consecutively, practically all of the water flowing out of the lakes into the St. Lawrence came from the recession of lake levels. The lake levels would therefore have to be allowed to recede, when the rainfall is deficient, to maintain the natural low-water flow in the Niagara and St. Lawrence rivers.

84. Similarly, when the lakes reach high stages, it is not possible to hold back more water for storage against a future low supply, without raising the Lakes to such extent as would do great damage to industries and lands on the lake shores.

85. The operation of regulating works must therefore be limited to holding back water in storage when the supply is in excess of the requirements of the Niagara and St. Lawrence rivers, and the stages of the lakes are at the same time such that the water can be stored without risk of causing excessively high levels. The water stored can subsequently be used for maintaining the outflow of the Niagara and St. Lawrence during periods of deficient supply without drawing down the Lakes as far as they would fall under present conditions.

86. The lake levels can be raised by compensating works to the extent regarded as justifiable with respect to high lake levels. With regulating works the range of stage can be reduced, so that, with the same high levels, the low levels will be higher than those secured by compensating works.

87. Regulation for Lake Navigation. To determine the extent of the benefit, a program of regulation was formulated by the Board, which was designed to secure, with as complete a control over the outflow of the lakes as is at all practicable, the maximum improvement in lake levels, and at the same time assure a minimum discharge of 176,000 cubic feet per second out of lake Erie and 200,000 cubic feet per second into the St. Lawrence river. The natural discharge heretofore has fallen below these figures but 5 per cent and 15 per cent of the time, respectively. This program was then applied to conditions that actually occurred on the lakes during the period from 1894 to 1925, inclusive. Considering only the levels affecting navigation, and eliminating the fluctuation in the natural stages which were due to progressively increasing diversions and outlet enlargements, the results are as follows:—

Lakes	Range of stage of Lakes as regulated	Range in stage if not regulated	Gain by regulation
	Feet	Feet	Feet
Superior	2·4	2·8	0·4
Michigan-Huron	2·4	3·5	1·1
Erie	2·8	3·3	0·5
Ontario	2·8	4·2	1·4

88. The mnimum cost of regulating works necessary to put the program into effect is estimated at $36,400,000. The cost of securing the same improvement in lake channels and harbours by compensating works supplemented by dredging is $13,400,000, it being assumed that the dredging is undertaken in both cases as a part of the comprehensive project for channel enlargement. It is clear, therefore, that the construction of regulating works for the benefit of lake navigation is not economically justified.

89. Moreover, regulation works in the St. Clair river will necessarily be a burden to its present intensive water traffic. A preliminary investigation indicates that the control over the discharge of the river necessary to regulation could be obtained by a series of works, each with an open navigable pass having a width, depth, and current velocity suitable for navigation, and the estimate of $36,400,000 is based on such a scheme. The scheme involves the maintenance of many miles of channel at the predetermined dimensions necessary to accomplish the result, and its practicability is not assured. It would certainly afford a waterway less convenient for navigation than are the present free channels. The somewhat more expensive plan that has been advanced, of works in which locks would be provided to pass vessels at the regulating works, would be more certain of operation, but would inflict a serious loss on present commerce through the delay of lockage. The total delay for each vessel passage, including the time lost in approaching the lock and delays awaiting lockage, would be approximately one hour. The aggregate economic loss resulting from such a delay to the great vessel movement through the waterway would be in the vicinity of $1,000,000 per annum.

90. Furthermore, an analysis of the outflow from the lakes afforded by the program of regulation tested shows that, while the lowest outflow would be somewhat increased, the discharge would be held down to a lower flow than now occurs for nearly half the time, in order to build up the lake levels. As explained in Appendix B, a prolongation of the periods of low discharge disproportionate to the increase in the minimum discharge is an inevitable conse-

quence of the restricted discharge capacity of the lake systems. Aside from the effect on the future development of power, such long-continued low discharges would have serious consequences in reducing the water levels in Montreal harbour.

91. Various modified programs for regulation were tried out, but all with the same result; such improvement in lake levels as could be secured was at a cost greatly in excess of the saving effected in future channel and harbour dredging, and at the expense of prolonging the periods of low flow in the St. Lawrence.

92. Regulation for Power. While the general regulation of the Great Lakes is clearly inadvisable for the purpose of improving the lake levels for lake navigation, there remained a question whether it might be justifiable for the purpose of increasing the flow for power on the St. Lawrence. A study was made, therefore, to determine the results that could be expected if the operation of the works was directed toward that end, instead of toward reducing the fluctuations in the levels of the lakes. While the outflow could be thus redistributed to increase the primary power potentially available, no program of regulation was found that would increase materially the total output of plants with an installed capacity sufficient to utilize the mean flow of the river. The advisability of undertaking the regulation for the benefit of the power on the St. Lawrence depends, therefore, wholly on the nature of the market for power that may develop as the installation of power works proceeds. The regulation of lake Ontario alone will afford a sufficent control over the flow of that river for the advantageous development of power until at least the enormous amounts available without further regulation is absorbed. There is, therefore, no present justification for the great expenditure necessary to provide regulating works in the interest of power production.

93. General Aspects of Regulation. Regulation works could be administered to serve either of two divergent purposes. They could be used to decrease the fluctuations in the lake levels for the benefit of navigation and of riparian interests on the Lakes, at the expense of the outflow into the St. Lawrence; or they could be used to improve the outflow into the St. Lawrence for the benefit of power production and of navigation in the lower river, at the expense of the levels of the Lakes. The predominant interests concerned in the levels of the Great Lakes are in the United States; the predominant interests concerned in the outflow into the St. Lawrence are in Canada. Lake regulation might therefore, create points of difference between various interests in the two countries. It is not even possible to fix in advance a definite allocation of such benefits as might accrue from lake regulation, because any program of regulation must be based on past experience as to the supply of water to the lake system. If a future deficiency in supply should exceed past records in extent and duration, the question would arise whether the emergency should be met by holding back water in the lakes at the expense of the St. Lawrence, or whether the navigable depth in Montreal harbour is to be maintained at the expense of lake navigation.

94. The regulation of lake Superior has been satisfactory to the two countries for the reason that the fluctuations introduced in discharge from that lake are absorbed in the great reservoir formed by lakes Michigan and Huron without greatly affecting the levels of the latter or materially affecting the discharge of the Niagara and the St. Lawrence rivers. The recent great deficiency in supply to lake Superior, which was not anticipated when the program for regulation was drawn up, gave rise, therefore, to no special complications.

The regulation of lake Ontario, proposed as a necessary part of the improvement of the St. Lawrence, affects but one lake only, which has but 8 per cent of the area of the Great Lakes system. Its regulation will not affect in any substantial manner divergent national interests, and is a relatively minor problem, whose solution offers no serious difficulties. The regulation of the lakes as a whole is an entirely different matter.

95. COMPENSATING WORKS. The investigations made by the Board show that it is advisable to construct compensating works in the Niagara and St. Clair rivers to counteract the effect of all diversions and outlet enlargements on the levels of lakes Michigan, Huron, and Erie.

96. WORKS PROPOSED, NIAGARA RIVER. The works proposed in the Niagara river are located just above the contracted section of the river at Fort Erie, and in effect merely prolong this contracted reach. A longitudinal dyke, approximately one-half mile in length, is to be constructed to secure the required contraction. It is to be connected with the Canadian shore by a weir with its crest slightly below low-water-level, which will force practically all of the flow through the contraction at low lake levels, and a less proportion of the flow at high lake levels. The structures will not interfere with the free passage of ice, nor with such light-draft navigation as follows the river instead of using the Black Rock canal. In view of the approaching opening of the new Welland ship canal, with an increased diversion for its operation, they are designed to raise the low levels of lake Erie by 0.7 foot and the high levels by a slightly less amount. Should the amounts of the present or prospective diversions be reduced, the works can be altered at small cost to balance the reduced diversion. The cost of these works is estimated at $700,000.

97. WORKS PROPOSED, ST. CLAIR RIVER. The works proposed on the St. Clair river are a series of submerged rock sills with crests 30 feet below the low-water stage of the river. It has been shown in paragraph 77 that present diversions and outlet enlargements have lowered the levels of lakes Michigan and Huron by 1.15 feet. The Board regards it as safe to restore them to the extent of one foot. The back-water effect of the compensating works proposed in the Niagara river is computed as 0.15 foot on lake Huron. It is estimated that 31 sills in the St. Clair river, will secure the remaining 0.85 foot of compensation proposed, at a cost of $2,700,000.

98. This form of compensating works is selected primarily for the reason that the sills will not reduce the navigable width of this important waterway, nor will they increase the cost of providing a channel depth of 30 feet. While these works once built cannot be altered readily to meet a future reduction in the amount of the Chicago diversion, yet on account of the commercial value of the gravel in the river bed, it would not be costly to again enlarge the capacity of the river to meet such a reduction.

99. CONSTRUCTION PERIODS. To avoid an unwarranted reduction in the flow of the Niagara and St. Lawrence rivers while the lakes are being raised by the compensating works, the construction on the Niagara river should be spread over two years, and on the St. Clair river over four years' time, and the prosecution of the latter should be suspended during any extreme low-water periods that may occur at the time they are undertaken.

100. COMPENSATION FOR AUTHORIZED DIVERSIONS ONLY. The proposed compensating works will counteract not only the effect of diversions authorized by license in the United States and Canada, but also the effect of outlet enlargements, diversions for navigation, and diversions not covered by license. The

lake levels could be restored by similar but less extensive works to the extent that they have been reduced by diversions authorized by license in the two countries. The cost of such works would be nearly proportional to the amount of compensation of level effected, and is estimated as follows:—

Diversion compensated for	Cost of works in Niagara River	Cost of works in St. Clair River
	$	$
Chicago Sanitary District	400,000	1,350,000
Power diversions, Welland Canal	100,000	

COST OF DEEPENING CHANNELS THROUGH AND BETWEEN THE LAKES

101. An uncompensated enlargement of the navigation channels through the St. Clair and Detroit rivers would slightly increase the discharge capacity of these rivers and hence will tend to lower the levels of lakes Michigan and Huron. On the Detroit river an enlargement can be compensated by the deposit of the excavated material. On the St. Clair river some additional compensating works will probably be required. The cost of these, to counterbalance the excavation of a channel to a depth of 25 feet, is estimated at $200,000.

102. The cost of improving the channels between lake Erie and lake Superior to secure a depth of 25 feet below the levels which past experience indicates will be available 99 per cent of the time during the navigation season, after compensating works have been constructed, is as follows:—

TWENTY-FIVE FOOT CHANNEL.

Cost of compensating works	3,600,000
Cost of excavation	41,100,000
Total	$44,700,000

The present project for the new Welland ship canal, when completed, will give this depth of 25 feet between lake Erie and lake Ontario.

103. The estimates are based on the deepening of present channels, with such minor enlargements and straightening as experience with these channels has proved necessary. The lake levels on which the depths are based are:—

Lake Superior	601.0
Lakes Michigan and Huron	579.0
Lake St. Clair	573.75
Lake Erie	571.0

The estimates do not include a new lock in the St. Marys river, since the available depth in two locks last built by the United States, the Davis and Fourth locks, is 24 feet when lake Huron is at the level chosen as a basis for this improvement. The additional depth provided in the 25-foot channels is no more than is required for safe and convenient navigation.

104. The estimates show that a saving of approximately $1,250,000 will be effected in providing channels 25 feet in depth through and between the lakes by including compensating works in the project as proposed, rather than by securing the depth by dredging only. The construction of these compensating works will

afford also increased depth in all the harbours, large and small, on lakes Michigan, Huron, and Erie, and will reduce the cost of improving such harbours as may be deepened to correspond with the enlarged interlake channels. Moreover, without compensating works, the low-water depth in the Davis and Fourth locks at St. Marys falls will be but 23 feet. The construction of compensating works is therefore fully justified.

105. The costs of channels 27 and 30 feet deep, respectively, through and between the lakes at the same lake levels as those on which the channel 25 feet deep is based, are as follows:—

FOR A TWENTY-SEVEN-FOOT CHANNEL

Compensating works, Niagara and St. Clair rivers	3,700,000
Channel excavation, lake Erie to lake Superior	54,900,000
Lock in St. Marys river	6,500,000
New Welland ship canal, in addition to present project	1,100,000
Total	$66,200,000

FOR A THIRTY-FOOT CHANNEL

Compensating works, Niagara and St. Clair rivers	3,800,000
Channel excavation, lake Erie to lake Superior	75,900,000
Lock in St. Marys river	6,500,000
New Welland ship canal, in addition to present project	14,100,000
Total	$100,300,000

The studies made by the Board relating to lake levels and outflow, and to works for their control, will be given at length in Appendix B.

PART III

THE IMPROVEMENT OF THE ST. LAWRENCE RIVER

106. This part of the report sets forth the plans presented by the Board for the improvement of the St. Lawrence river for navigation and power, between lake Ontario and Montreal Harbour.

DESCRIPTION

107. For convenience of reference, the Board will use the following names to designate the five sections into which this part of the river naturally divides itself. In order downstream these are:—

The Thousand Islands Section (Fifth Division of the Report of 1921), embracing the deep, lake-like reaches of the river, 67 miles in length, from lake Ontario to the first swift water at Chimney point, 3 miles downstream from Ogdensburg, N.Y., and Prescott, Ont.

The International Rapids Section (Fourth Division of the Report of 1921), embracing the 48 miles of rapids and swift water between Chimney point and the head of lake St. Francis.

The Lake St. Francis Section (Third Division of the Report of 1921), extending 26 miles through that lake to the end of deep water at its foot.

The Soulanges Section (Second Division of the Report of 1921), embracing the 18 miles of rapids and shoal water from lake St. Francis to lake St. Louis.

The Lachine Section (First Division of the Report of 1921), embracing lake St. Louis and the rapids and shoals from this lake to Montreal Harbour, a length of 23 miles.

108. The first two sections lie along the international boundary, between the province of Ontario and the state of New York. The remaining three lie in the province of Quebec. The improvement of the Thousand Islands Section and of the Lake St. Francis Section is solely a question of excavating channels for navigation. The other three sections can be improved for power in addition to navigation.

GENERAL FEATURES OF PLANS

Navigation

109. Fundamental Principles. The plans have been prepared in accordance with the recognized principle that the interests of navigation on the St. Lawrence are paramount. A full observance of this principle does not interfere with the beneficial use of the flow of the river for power generation. On the contrary, the improvement of the rapid sections of the river for the joint benefit of navigation and power affords, as a rule, much better navigation than could be secured by the improvement now economically justifiable in the interest of navigation alone.

110. In accordance with its instructions, the schemes presented by the Board are designed to provide to the best advantage, at this time and ultimately, for the development of the capacities and possibilities of the waterway. The magnitude of the interests in the two countries that would be affected

by the improvements if the project be adopted have been fully considered. The Board has visualized the fullest ultimate development of the navigable capacity of the waterway commensurate with cost. The endeavour has been made to provide the maximum amount of open-river navigation, with a minimum of locks and of canal navigation. For the initial improvement it has adopted the minimum standards hereinafter set forth, but the plans are so drawn that the navigation improvements can be enlarged, at the least economic loss, as the traffic justifies further improvement. Plans that would restrict the best eventual development of the waterway for navigation have therefore been discarded.

111. Channel Depth. Conforming to the tenor of the instructions, the estimates are based on navigation channels 25 feet in depth. The sills of all locks and fixed structures are placed at 30 feet depth to permit of the future enlargement of the waterway. The Board has given careful consideration to the question whether it would be advantageous to provide initially for a channel depth other than 25 feet (Question 9 of Instructions). A majority of the Canadian Section favour the initial excavation to a depth of 27 feet. This is the depth to which the new Welland ship canal is being carried under the present contracts, and to which the sections of the canal previously excavated can be enlarged at relatively small cost. A majority of the United States Section regard the depth of 25 feet as sufficient initially, in the view that a project for a greater depth through the interlake channels above lake Erie is not foreseen for a long period. To afford full information on which to base the determination of this broad question of economic policy, the Board presents, in the summaries at the end of this part of the report, the estimates of the additional cost of excavating the channels initially to 27 feet; of the saving effected with an initial depth of 23 feet; and of the cost of subsequently enlarging the channel from 25 feet to 30 feet. Estimates for channels 23 feet deep are included, since such channels would accommodate comfortably all shipping that can use the existing interlake channels above lake Erie. The designs herein presented, and the alignment of the channels, are not affected by the depth to which the channels are excavated initially.

112. To remove any confusion between the depth of the channels and the draft of the vessels which can use them, the Board points out that channels 25 feet in depth are suitable for safe and convenient navigation by vessels of not to exceed 23 feet salt-water draft, and channels 27 feet in depth by vessels of 25 feet salt-water draft. For vessels of this size fresh-water draft exceeds salt-water draft by from 6 to 7 inches.

113. Standards for Channels and Locks. The Board recommends and has adopted the following standards for navigation improvements:

Channels for navigation have a minimum width of 450 feet, except in canal sections, where they have a bottom width of 200 feet (at 25-foot depth). Open channels are widened where advisable on account of cross currents and at bends, and are both widened and deepened as required to afford suitable current velocities for navigation. The minimum radius of curvature of the channels is 5,000 feet.

The locks conform in dimensions with those in the new Welland ship canal, and have chambers 859 feet in length between inner quoin posts, and 766 feet between breast wall and fender. The clear width of the locks is 80 feet, and the depth over the sills 30 feet. Duplicate sets of gates are so provided that two gates may always be closed against the upper level. Fenders will afford an additional safety precaution, and guard gates or emergency dams are provided when necessary to afford a means for stopping the flow that would result

from the accidental destruction of any lock gates. The plans are so drawn that all locks can be duplicated as commerce requires additional facilities, and the estimates include the foundations for duplicating all flight locks, since these have less ultimate traffic capacity than single locks.

114. Capacity of Waterway. The 25-foot waterway as designed has an estimated traffic capacity of 24,000,000 tons per annum after any flight locks included in the adopted plans have been duplicated. Flight locks are included in alternative plans for the improvement of the Soulanges Section only. With these alternative plans the initial capacity of the waterway would be 16,000,000 tons per annum until the duplicate locks of the flight were completed, after which the traffic capacity would be 24,000,000 tons, established by the capacity of the separate lock of the system having the highest lift.

Power

115. Power Installations. The plans provide for an initial construction of power plants based on conservative estimates of the rate at which power can be marketed under restrictions as to exportation. The demand for power the world over is growing rapidly and the great potential power of the St. Lawrence river may well become an important factor in the economic welfare of the two countries. The Board has therefore drawn its plans with especial view to the eventual utilization of the complete power resources of the river.

116. The various power houses have the capacity for the development of the maximum flow which the Board considers as utilizable in the future. The interests of navigation require that the flow down the St. Lawrence be maintained at a high degree of uniformity, and prevent the maximum use of water for power by fluctuating the hourly flow to meet the fluctuating power demand. An installed capacity well in excess of the minimum flow of the river has been provided, however, since the increasing value of power will justify its eventual development from the flow available during high-water periods only.

117. The ultimate installation proposed by the Board in the International Rapids Section is somewhat less than the installation proposed by some of the applicants for authority to develop power in this section. The excess installed capacity provided in the plans of these applicants would afford little return on account of the limits inherent in the regulation of flow required in the interests of navigation and of power downstream.

118. The initial installation of power machinery in each power house will depend on the market available when the works are put in operation. For purposes of estimating the initial expenditures required, the initial installation is taken at 50 per cent of the eventual capacity of the power houses first constructed.

119. Winter Power Operation. A full study has been given to the winter operation of power plants. The fundamental problem is found to be the maintenance of the winter discharge capacity of the river without excessive loss of head from gorging with ice, rather than the local problems of handling the ice at the power plants themselves.

120. The power sections of the river now have so rapid a current that (with an exception elsewhere noted in this report) they always run open throughout the winter. From the time that the water reaches the freezing point, in late December or early January, until the end of winter, these exposed reaches are continuously losing heat and making ice, in the form of frazil and anchor ice.

Frazil is the term applied to the particles of ice forming in water where the current prevents the formation of a surface ice sheet. These particles agglomerate in pans of soft, snow-like ice, which float down the surface of the river. Anchor ice is the ice forming on the bed of the river, due to the loss of heat by radiation. It rises to the surface when loosened by the heat of the sun, and floats downstream in masses resembling frazil ice. The term "slush ice" is often applied to both. The masses of slush ice are carried down by the current and pack under and against the ice sheet formed over the quiet water at the foot of the reach, gorging the channels to such an extent that rises in the water level of from 10 to 30 feet occur in winter at the foot of each open section.

121. The construction of a dam in any of the power sections for the dual purpose of concentrating head for power development and of improving the river for navigation will, in the general case, create a deep slow-flowing pool, certain to freeze over early in the winter. The situation to be guarded against is the throttling of the river by the gorging of the channel at the upper end of this frozen pool. It is established by the Board from measurements of the loss of heat from the river, confirmed by measurements of the ice actually formed, that, with the temperatures obtaining in the region, from 15 to 20 cubic feet of ice will be made in the course of a severe winter for every square foot of open water. It is found, however, that in all cases where the current velocity is as low as 2.25 feet per second, the frazil and anchor ice consolidates on the surface when it meets an ice sheet, and extends this sheet upstream, without the excessive gorging and throttling of the river that occur at higher current velocities. The plans for power development are therefore based on enlarging the upper reaches of the power sections by excavation where necessary to insure, with the discharges that must be maintained in winter, current velocities not exceeding 2.25 feet per second, except through short distances at the upper ends of the power reaches where the remaining area of open water could not produce enough ice to be of serious consequence. Such ice as may be formed in these short distances would be stowed in nearby enlargements of the river below.

With an ice sheet extending down to the intakes of the power houses, the operation of the power plants will be nearly, if not entirely, free from ice difficulties.

122. Modification of Plans during Construction. In such an extensive project as that for the improvement of the St. Lawrence it is not possible, even in the time consumed by the Board in its investigations, to arrive at the best possible design of all features of the project, both for navigation and for power. The estimates are based on safe and adequate structures and channels, but it is expected that the responsible authorities in charge of the construction will exercise the usual latitude in making such alterations as are found to be desirable in consequence of more detailed studies, and the development of the art.

123. Datum Plane used in Report. All elevations in this report are elevations above mean sea-level. The precise reference planes used are described in Appendix C.

THOUSAND ISLANDS SECTION

(Fifth Division of Report of 1921)

124. This section, 67 miles in length, extends from Tibbets point, taken as marking the end of lake Ontario, to Chimney point, 3 miles downstream from the towns of Ogdensburg, N.Y., and Prescott, Ont. The river is generally

broad, deep and slow flowing, with a total fall at mean stage of but about one foot. Between Clayton, N.Y. (mile 20) and Brockville, Ont. (mile 52) a number of granite reefs endanger navigation, and the narrow deep channels through the Thousand Islands and the Brockville group require some straightening for safe and convenient navigation by deep-draft vessels. The improvement proposed is the removal of twelve reefs and the cutting back of four projecting points, all to a depth of 25 feet below a datum plane corresponding to elevation 242.5 on lake Ontario. The cost, determined from a detailed survey made by the present Board, is $1,100,000. Details of the estimate are given in Appendix C.

125. The work recommended follows the same lines as that proposed in the Report of 1921, but the estimated cost is greatly increased on account of the more accurate data secured since that report.

INTERNATIONAL RAPIDS SECTION

(Fourth Division Report of 1921)

126. Description. This section extends from Chimney point (mile 67) to Colquhoun island (mile 115), opposite St. Regis, at the head of lake St. Francis, a distance of 48 miles. The river here runs in a succession of rapids, beginning with the Galop rapids, near the head of the section, and ending with the Long Sault rapids (miles 103 to 104), with the Rapide Plat just above Morrisburg, about midway between. Swift currents predominate in the reaches between the rapids and extend to the middle of Cornwall island (mile 111). The total fall through the section at mean river stage is 92 feet, of which approximately one-third occurs in the first 18 miles above the foot of the Rapide Plat at Ogden island, and the remaining two-thirds below that point. The present 14-foot navigation on the river is carried around the rapids by a series of side canals along the Canadian shore.

127. Prior Plans. The improvement proposed in the Report of 1921 was the construction of a dam in the Long Sault rapids which would raise the water level to elevation 231, creating a pool reaching into the Rapide Plat at Ogden island. At Ogden island a second dam with a lock was to be constructed, which with suitable channel enlargements would carry navigation through the upper part of the section. A canal along the Canadian shore, 8 miles in length, with two locks, was to carry navigation from the pool formed by the lower dam back to the river at the town of Cornwall. The plan included the development of power at a Canadian and an American power house located at the foot of Barnhart island, with a head of 74 feet and a total installed capacity of 1,777,360 horse-power. In addition, a second power plant with a capacity of approximately 60,000 horse-power, located near the head of Long Sault island, was to develop the surplus head of 29 feet created in the diversion which feeds the power plant of the St. Lawrence River Power Company at Massena, N.Y. The head available at the upper dam at Ogden island, amounting to about 8 feet during the ice-free months, was not to be developed for power. It was estimated that most of this head would be absorbed in winter by the increased river slope due to ice conditions. The structures creating the lower pool were, however, to be so designed that the pool level could be raised to recover a part or all of the head lost at the Ogden island dam, if desired at a future time.

128. Plans Proposed. The present Board concurs in the opinion that the improvement of the International Rapids Section should include the development of power. Its length is such that a side canal for navigation would be extremely costly and would impose an unnecessary hindrance to shipping.

129. The Board has given extended study to various plans for improving the river for power and navigation, including those presented by the Hydro-Electric Commission of Ontario and others to the International Joint Commission in 1921 and those recently submitted by American Corporations to the Water Power Commission of the State of New York.

130. The Board is of the opinion that the plan presented in the Report of 1921, although in a general sense practicable, should be modified to secure more dependable winter operation and to assure the fullest practicable utilization of power resources of the river.

131. Two plans meeting these requirements have been prepared by the Board, one for a single-stage development, with a dam and power houses in the vicinity of Barnhart island, at the foot of the reach, but with control gates at Galop island at the head of the reach, except across the channel provided for navigation.* The second scheme is for a two-stage development, with two pools, the upper pool formed by a dam and power house at Ogden island, just above Morrisburg, and the lower pool (at normal elevation 224) by a dam and powerhouses at Barnhart island.**

132. Navigation. With the single-stage development, navigation enters the pool through a free channel from the upper river, and passes from the lower end of the pool through a canal, with two locks, on the United States side of the river, which leads to the south channel at Cornwall island, thence a free channel leads to lake St. Francis. With the two-stage development navigation similarly enters the upper pool through a free channel, passes from the upper to the lower pool through a lock at Odgen island, and from the lower pool to the south channel at Cornwall island by a canal with two locks as in the single-stage scheme. The two-stage scheme requires one more lock than the single stage.

133. Available Heads, Single Stage Plan. The levels of the pool of the single-stage development, during the ice-free months, after the full estimated channel enlargements have been made, will vary normally between the limits of elevations 240 and 244, depending on the level of lake Ontario and the flow of water determined by the program of regulation. The tail-water elevation will be about elevation 157. Further channel enlargement below the power houses may lower the tail-water somewhat and add to the head, but the increased power made available is not considered in this report. The normal summer head at the power houses of the single-stage development will therefore be about 85 feet. The increased slope of the pool in winter due to ice retardation is expected to amount to about 6 feet, and a rise of about 4 feet in the tail-water levels is anticipated from the increased slopes below the power house, so that the net winter head expected is about 75 feet.

134. Available Heads, Two-stage Plan. With the two-stage development, the lower pool will be kept closely to elevation 224, both summer and winter, giving a summer head of 67 feet and a winter head of 63 feet. The summer levels of the upper pool at the Ogden island power houses will range between elevations 241 and 245. On account of the slopes of the lower pool, the summer head at the Ogden island power houses will be about 17 feet. A winter head of 12 feet is expected. The plans and estimates provide for the utilization of a head of 21 feet temporarily during the period between the completion of the upper and lower plants, respectively.

* The plans provide for partly closing the navigable channel by control gates, leaving a free opening for navigation at least 450 feet in width.

** Attention is directed to an alternative two-stage project which was prepared after Par. 131 to Par. 156 of this Report was presented in November, 1926. In the alternative project, the upper dam is placed at Crysler Island instead of at Ogden Island. It is described in Appendix "C," Par. 120 to Par. 134.

135. Maximum Installed Capacities. The maximum flow which the Board regards as eventually utilizable at the Barnhart island power houses is 245,000 cubic feet per second at winter head. The equivalent capacity at summer head in the single-stage development will be 261,000 cubic feet per second, and in the two-stage development 252,000 cubic feet per second. The utilization of such large flows will not be economically justified at the Ogden island power houses of the two-stage development, and the ultimate installation at these power houses is based on a flow of 212,000 cubic feet per second at winter head, equivalent to 240,000 cubic feet per second at summer head. The installed capacity of the power houses of the single-stage development based on the summer head and flow, and, including spares, is 2,326,000 horse-power. The installed capacity of the two-stage development, on the same basis, is as follows:—

Lower power house, Barnhart island	1,808,600 horse-power
Upper power house, Ogden island	406,400 horse-power
Total	2,215,000 horse-power

136. The fact must be appreciated that the additional capacity proposed in the single-stage development is not a measure of power which can be delivered. Except for the slightly less efficiency of the machinery of the Ogden island power houses, which would not materially affect the total, the power that can be delivered depends on the flow of water available, which will be less than the installed capacity of the plants for the considerable part of the time.

137. Winter Operation, Single-Stage Plan. As for winter operation, the pool formed by the single-stage development is so wide and deep as far upstream as Ogden island that an ice cover will form over it promptly. The plans and estimates provide for the eventual enlargement of the constricted portions of the river from Ogden island as far upstream as Lotus island (at the foot of the Galop rapids), to the extent necessary to secure current velocities not exceeding 2.25 feet per second, in order to assure satisfactory ice conditions in winter. The contracted section from the foot of Lotus island to the head of Galop island, 2.5 miles in length, is to be given the area required for satisfactory navigation only, and is expected to have an open channel in winter; but the extent of this open water would be too limited to be of serious consequence in winter operation.

138. The amount of channel enlargement required to assure satisfactory winter operation cannot be predicted in advance with certainty. It is proposed to execute initially only such enlargement as is necessary to insure satisfactory navigation conditions, and to prosecute this enlargement after the pool has been created, when dredging can be done more advantageously, until satisfactory winter operation is secured. The control of the head through the section afforded by the control gates at the Galop will afford a means for insuring the winter discharge capacity of the river during this period.

139. Winter Operation, Two-Stage Plan. In the two-stage development some enlargement of the channels in the 8-mile reach between Ogden island and Weavers point is required to secure the desired low current velocities to assure winter operation. Above Ogden island the enlargement required will be identical with that required in the single-stage development. This enlargement must be completed before the complete scheme is put in operation, in order to ensure control of the winter flow and provide uninterrupted power at the Ogden island plant.

140. Control of Ferry Operation. Is is assumed that proper control will be exercised over the ferries operating between Ogdensburg and Prescott to prevent the ice situation from being aggravated by the breaking up of the ice sheet between these towns and Galop island by these agencies.

141. Costs. The cost of the single-stage development, including the full channel enlargement to insure satisfactory winter operation, is estimated at $235,000,000. The cost of the two-stage development is estimated at $264,600,000.

142. Recommendations. The United States Section of the Board recommends the single-stage development as affording better navigation by eliminating one lock, and obtaining slightly more power, at a cost of $29,600,000 less than the cost of a two-stage development.

143. The Canadian Section of the Board recommends the two-stage development on the ground that it can be carried out in two parts, so that the power from the upper development can be developed and marketed before the whole of the improvement is completed. It believes that for this reason its overall cost, including interest charges, will not be as greatly in excess of the single-stage development as appears from the comparative costs without interest charges. It believes that the control over the flow of the river will be better assured. The flowage of land will be reduced from about 28,000 acres to about 18,000 acres.*

144. Location of Barnhart Island Dam and Power Houses. Whatever plan be adopted, there is a choice of sites for the dam and power houses in the vicinity of Barnhart island that create the pool of the single-stage development, or the lower pool of the two-stage development. A suitable site for the dam exists at the foot of the Long Sault rapids, on an arc extending from the head of Barnhart island to the foot of Long Sault island and thence to the United States shore. With a dam at this site, the channel between Barnhart and Sheek islands would be utilized as a forebay channel to the power houses, which would be located at the foot of Barnhart island. This general arrangement was contemplated in the Report of 1921. For the 224 two-stage development it is proposed to supplement the capacity of this forebay channel by utilizing also the channel known as Bergen lake, between Sheek island and the Canadian shore. The low banks prevent the use of this channel for that purpose at the high levels of the single-stage development.

145. With the dam built at the foot of Long Sault island, the navigation canal from the pool would leave the river at the middle of Long Sault island. It would be 6.9 miles long.

146. The second site for the dam is across the main river at the foot of Barnhart island. The foundation rock is here quite deep. With a dam at this site the navigation canal would leave the river at Robinson's bay, and its length would be reduced to 2.9 miles. The power houses would be adjacent to the dam. Two alignments for the dam and power houses at this location are shown on the plans, either of which is regarded as satisfactory.

147. The United States Section prefers the location for the dam at the foot of Barnhart island, since it reduces the length of the navigation canal, reduces the chance of local ice difficulties in winter (since the section of the pool above the power houses is ample to insure a firm ice cover), and simplifies operation through the juxtaposition of the dam and power houses. The Canadian Section

* The above acreages include all lands the purchase of which is contemplated in the estimates. The area of land actually inundated at maximum emergency levels, including the inundated portions of islands, will be 22,000 acres and 12,000 acres respectively.

prefers the location at the foot of Long Sault island on account of the higher rock foundations there found, which it believes will lessen construction difficulties. The choice between the two locations is regarded as a matter of detail, to be settled by the constructing agencies after the general type of development has been determined.

148. The plans for the single-stage development submitted with this report show the dam across the main river channel at the foot of Barnhart island. Those for the two-stage development show it at the foot of Long Sault island. In the opinion of the Board either location can be used with either development.

149. Control of Flow. Whether the single-stage or the two-stage development is finally selected as best meeting the joint interests of the two countries, the Board points out that the use of water at the power houses and the operation of the sluice gates, which with the wheels control the flow of the river, should be under the control of an international board. That board should be clothed with full authority to take such measures as will insure the regularity of flow that is necessary in the interest of navigation in the lower river, and of the power houses downstream; and to insure such flows as will maintain the levels of lake Ontario within proper limits, while preserving the volume of flow required to prevent injury to navigation at and below Montreal.

150. Alternative Plans Considered. Of the various alternative plans for the improvement of the International Rapids Section submitted to the International Joint Commission in 1921, the one requiring especial consideration at this time is that for navigation and power development proposed by the Hydro-Electric Commission of Ontario and designated as Scheme " B ". This provided for a two-stage development broadly on the same lines as those proposed by the Canadian Section herein, except that the lower pool was to be held at elevation 210, or 14 feet below the elevation proposed in this report. At this low elevation a large amount of excavation would be required to secure suitable channels for navigation through the lower pool; and an enlargement to secure the low velocities regarded as necessary for satisfactory ice-covered winter operation would be excessively costly, and was not contemplated by the proponents. On the other hand, the higher head at the Ogden island power plants, amounting to about 30 feet, reduced materially the cost per horse-power of development of the upper head.

151. The operation of this scheme was based on maintaining an open channel through the river during the winter, and only such channel enlargements were proposed as would be necessary for navigation.

152. The cost, on estimates paralleling those herein presented for a single-stage and two-stage development, would be $254,000,000.

153. The studies of the Board, and its investigations of power plants operating under similar climatic conditions, show conclusively that it is neither feasible nor desirable to maintain an open channel through this section in winter when it is improved for power. Even with the present current velocities the ice has at various times caught across the river in the quieter reaches of the section, starting an ice pack which quickly attained large proportions and raised the river level by as much as 10 feet. The likelihood of the ice catching to form ice jams would be increased after the river has been improved, on account of the greatly reduced current velocities. It is certain that an open channel through this 35-mile stretch could not be maintained without ice breakers; and all experi-

ence shows that a reasonable number of ice breakers could not be depended upon to keep open continuously so long a channel under these conditions. If, however, an open channel were maintained by such means, the accumulation of ice below the power houses of the lower pool at Barnhart island would raise the tailwater level at these power houses to such an extent that their output would be greatly curtailed.

154. Other alternative plans presented to the Joint Commission in 1921 were for two-stage developments with the upper dam at Crysler island (6 miles downstream from the foot of Ogden island), and at Cat island (10 miles downstream from the foot of Ogden island). The further borings made at the Crysler island site show that the foundation conditions are not as good as were first supposed,* and the proponents of the Cat island dam site now prefer a full single-stage development broadly on the lines of that proposed by the United States Section herein.

155. Improvement for Navigation Only. The least expensive method developed for improving the river for navigatoin alone is through the construction of a side canal on the American shore from the Galop rapids to Ogden island. Navigation would there enter a pool, with water level at elevation 220, to be formed by a dam at the head of the Long Sault rapids, and from this pool pass to the south channel of the river at Cornwall island through a canal on the same line as that proposed for the two-stage development. The navigation provided by such a plan would be far inferior to that provided by either the single or the two-stage developments respectively proposed. The estimated cost is $79,000,000.

156. Summary. Two alternative schemes for the improvement of the International Rapids Section in the joint interest of navigation and power are presented by the Board as best providing for the development of the capacity and possibilities of this section.

Their respective estimated costs are as follows:—

(1) Single-stage Development—		
Works solely for navigation		22,000,000
Works common to navigation and power		106,500,000
Works primarily for power—		
Substructures and head and tail race excavation		42,000,000
Superstructures and machinery		64,500,000
Total cost (2,326,000 installed horse-power)		$235,000,000
Initial cost with installation of 1,163,000 horse-power (remaining installation deferred awaiting growth of market)		$203,000,000
Estimated initial expenditure to open navigation and provide 1,163,000 installed horse-power before channels are enlarged to ensure winter operation (See par. 137, 138)		$190,000,000
(2) Two-stage Development—		
Upper Pool—		
Works solely for navigation	8,093,000	
Works common to navigation and power	53,726,000	
Works primarily for power—		
Substructures, head and tail race excavation	23,737,000	
Machinery and superstructure	33,829,000	119,385,000

* "Additional borings, made since the preparation of this paragraph, have changed the conclusions of the Canadian Section of the Board, in regard to the Crysler Island dam site. See Appendix "C," Par. 120 to Par. 134."

(2) Two-stage Development—*Concluded.*		
Lower Pool—		
Works solely for navigation..............	25,388,000	
Works common to navigation and power..	37,130,000	
Works primarily for power—		
Substructures, head and tail race excavation	36,866,000	
Machinery and superstructure........	45,777,000	145,161,000
Total cost (2,215,000 installed horse-power)		$264,546,000
Rounded total		$264,600,000
Estimated initial expenditure to open navigation and provide 406,400 horse-power in upper plant and 756,600 horse-power in lower plant (remaining installation in lower plant deferred awaiting growth of market)....................		$238,400,000
Estimated initial expenditure to open navigation and provide 1,163,000 horse-power at lower plant (remaining installation at lower plant and all that of upper plant being deferred).		$214,500,000

These estimates exceed those given in the Report of 1921 because they provide a fuller power development, and more elaborate measures to ensure satisfactory winter operation, besides being based on the higher unit costs indicated by the detailed studies made by the present board.

LAKE ST. FRANCIS SECTION

(Third Division of Report of 1921)

157. This section extends from Colquhoun island opposite St. Regis (mile 115) to deep water at the foot of lake St. Francis (mile 141). The currents through the lake are sluggish, and the total fall through the section is about one foot. While the lake contains many shoals, deep channels extend through it. The work proposed is the dredging necessary to secure a suitable channel. It is on substantially the same lines as was recommended in the Report of 1921. The estimated cost, for a channel 25 feet deep below a datum plane having an elevation 151.5 at the head of the lake and 150.5 at its foot, is $980,000. The estimates differ by a small amount from those shown in the Report of 1921, principally because the limits of the section are slightly changed to conform to the modifications of the project in the International Rapids Section.

SOULANGES SECTION

(Second Division of Report of 1921)

158. Description. This section, 18 miles in length, extends from deep water in lake St. Francis (mile 141) to deep water in lake St. Louis (mile 159). The river falls from lake St. Francis to lake St. Louis in a succession of rapids, the Coteau rapids at the head, the Split Rock and Cascades rapids at the foot, and the Cedars rapids about midway. The total fall through the section at present mean stages of the two lakes is 83 feet.

159. Present 14-foot navigation passes through the Soulanges canal, paralleling the river on the north.

160. There are a number of existing power developments in this section, which are described in Appendix C. The most important is that at the Cedars rapids where a third of the low-water flow of the river is diverted through a headrace canal to a power house with an installed capacity of 197,000 horsepower, at 32-foot head.

161. Prior Plans. The improvement proposed in the Report of 1921 was a lateral canal, 15 miles in length, for navigation only, on the south side of the river, designated as the Melocheville-Hungry Bay Route. The report outlines a plan for navigation in conjunction with complete development of power, but contains the opinion that the rate of growth of the market for the large block of 1,560,000 horse-power afforded by the development was insufficient to justify its adoption.

162. Improvement for Navigation and Power. The Board finds that it is practicable and advantageous to combine the improvement for navigation in this section with the development of power on a progressive program of construction of power plants, only the first part of the power development being undertaken in conjunction with the works required to carry navigation through the section.

163. In brief, this plan provides for a dam at the head of the Cedars rapids, which will create a pool having a level from 1½ feet to 5 feet below the level of lake St. Francis. The shores of that lake are so low that the raising of its high-water levels would destroy large areas of agricultural land and, aside from the large cost involved, is highly undesirable. The plans therefore include an extensive enlargement of the discharge capacity of the Coteau rapids to insure that the backwater slope will not raise the high levels of the lake. Navigation passes from lake St. Francis to the pool by a canal around the Coteau rapids, 3 miles in length with a low lift lock. Even with the enlargement proposed, the currents in these rapids will be too swift for safe navigation, and especially for safe passage through the draw in the railroad bridge which here crosses the river. The canal has, however, been given such an alignment that it can be converted into an open channel when the traffic justifies the large additional cost. A second canal, 5 miles in length, with two lift locks, carries navigation from the pool to lake St. Louis. These locks may be either in flight or separated by a short pool. The difference in cost in favour of the separate locks is small.

164. The first part of the power development is the generation of a total of 382,000 horse-power at a power house with 22-foot head incorporated in the dam. The present Cedars plant will be continued in operation, water being fed into the headrace through sluice gates.

165. The second part of the progressive development now envisaged is the generation of 500,000 horse-power at 75-foot head at a power house located on the shore of lake St. Louis north of Cascades point, and near the Chamberry gully. It will be supplied through a headrace canal formed, in part, by the enlargement of the navigation canal.

166. The third part is the construction of a dam and power house, with a 53-foot head, at the Cascades rapids, at the foot of the section, which will develop a total of 974,000 horse-power. The present Cedars plant will then be put out of commission.

167. The estimated cost of these works is as follows:—

First part, including navigation works	103,945,000
Second part	37,291,000
Third part	63,816,000
Total	$205,052,000

168. The installed capacities in these plants, including spares, at normal summer heads are:—

First part	404,300 horse-power
Second part	545,000 horse-power
Third part	1,030,400 horse-power
Total	1,979,700 horse-power

169. If but one-half of the hydro-electric machinery is installed when the first part of the program is initially constructed, leaving the other half to be installed as the demand for power develops, the initial expenditure required to open navigation and provide 202,000 horse-power becomes $92,000,000.

170. Complete River Development. An alternative scheme which affords the maximum open river navigation warrants description. In this scheme two dams with power houses would be constructed initially, the upstream dam substantially on the line of the dam proposed in the first part of the recommended scheme, and the second dam and power houses at the Cascades rapids at the site of the structure forming the third part of the progressive power development therein contemplated. Navigation would pass from lake St. Francis to the pool formed by the upstream dam as in the recommended scheme. From this pool it would pass through a short canal and lock to the pool formed by the Cascades dam and power houses, thence through a lock directly to lake St. Louis. The 5-mile canal provided in the recommended scheme between the upper pool and lake St. Louis thereby would be eliminated.

171. The pool of the Cascades dam would be held at elevation 115, giving a 43-foot head between this pool and lake St. Louis, instead of the 53-foot head contemplated in the third part of the recommended project. This change would reduce the difference of levels to a conservative lift for a single lock. The power houses at the upstream dam would be so located as to develop the remaining 30 feet of head available in the section.

172. The scheme would entail the reconstruction of the existing Cedars power plant as a part of the initial work, instead of permitting a postponement until the last part of the power development program. Arrangement would have to be made to supply the present customers during the reconstruction period.

173. The total cost of this alternative scheme, with a complete eventual installed capacity of 1,948,000 horse-power, would be $194,317,000 exclusive of interest charges, or approximately $10,700,000 less than the cost with the plans recommended. On the other hand, the initial expenditure would exceed largely the initial expenditure required with the recommended plan. The initial power installation must include, in addition to such new power as is provided, an installation of 207,000 horse-power to replace power lost at existing plants, this being 197,000 horse-power at the present Cedars plant, and 10,000 at other plants. The initial expenditure required to open navigation and to provide an installation of 404,300 horse-power of new power, together with this replacement of power at existing installations, would be $123,400,000, against the minimum initial expenditure of $103,945,000 required with the same installation of new power under the recommended plan. Unless power can be sold more rapidly than the Board is led to believe, the interest charges on the $19,455,000 increased initial cost would overbalance the $10,700,000 difference between the ultimate costs of the completed projects indicated by the foregoing estimates. The scheme makes a maximum use of the river and merits serious consideration if a market for the large amount of power can be developed within a reasonable period.

174. Improvement for Navigation alone. The schemes studied by the Board for providing navigation alone are:—

(*a*) A lateral canal on the south side of the river extending from Hungry bay to Melocheville, substantially as recommended in the Report of 1921. Its estimated cost is now \$33,640,000.

(*b*) A lateral canal on the north side of the river, so designed as to conform to an eventual combined improvement of the river for navigation and power on the lines recommended by the Board. Essentially, this scheme embraces the construction of the upper and lower lateral canals proposed in the combined improvement, with a land canal connecting them, the latter to be abandoned when the river is improved for power. The estimated cost of the canal, complete, is \$40,378,000.

The part of the land canal that would be abandoned for navigation would be used in part for drainage. Its estimated cost is \$6,382,000. The estimated cost of the river connections is \$1,922,000.

(*c*) A river improvement as proposed in the recommended scheme, with substructures for power plant, but without power installation. Its estimated cost is \$78,515,000.

175. *Conclusions.* The Board unites in the view that the navigation improvement combined with the progressive development of power (paragraphs 162 to 169) hereinbefore set forth better provides for the present and future development of the waterway than any scheme for navigation alone, and is therefore the desirable scheme, if arrangements are made whereby power interests bear a fair proportion of the cost of the initial expenditure required.

176. If it be found impossible to arrange for such co-operation in meeting the initial cost, a majority of the Canadian Section favour the construction of the lateral canal on the south side of the river (Melocheville-Hungry Bay project) which is the least expensive means for providing navigation. The United States Section submits the view that a route designed to serve so large a territory will demand eventually the freer navigation of an open river. It believes, therefore, that even if arrangements cannot be made for the participation of power development in the initial improvement, it will be better to adopt the river development (navigation scheme *c*) or a canal on the north side capable of conversion into a river development (navigation scheme *b*) rather than the Melocheville-Hungry Bay route, the investment in which would largely be lost when a river development is adopted.

177. A detailed description of the works proposed in the combined navigation and power project recommended, including those necessary to prevent undue flowage, with detailed estimates of cost, and a discussion of alternative schemes and their relative economic values at various rates of power consumption, are given in Appendix C. A general analysis of the estimated cost of the initial part of the recommended combined navigation and power project is as follows:—

Works solely for navigation	31,594,000
Works common to navigation and power	34,686,000
Works primarily for power—	
Substructures, and head and tail race excavation	13,079,000
Superstructure and machinery	24,586,000
Total	\$103,945,000
Cost with initial installation of one-half of power machinery	\$92,000,000

LACHINE SECTION

(First Division of Report of 1921)

178. Description. This section extends from deep water at the head of lake St. Louis (mile 159) to Montreal harbour (mile 183). The first 11 miles are through the deep water in the upper part of the lake; the next four miles are through the shoal water at its foot. From the foot of the lake, the river runs 5 miles with swift currents, through a channel badly obstructed with rock reefs, to the Lachine rapids. It drops through these rapids to the La Prairie basin, a wide expanse of shoal water, 5 miles in length; thence falls through a mile of shoal, swift running channels, to Montreal harbour. The total fall through the section is about 48 feet, of which 9 feet is between the upper end of lake St. Louis and the head of the Lachine rapids, 24 feet through these rapids, 4 feet through the La Prairie basin, and 11 feet between the La Prairie basin and Montreal.

179. The course of the river from lake St. Louis to Montreal harbour describes a wide bend to the south. The present 14-foot navigation passes through the Lachine canal, which cuts through the city across this bend.

180. In this section the St. Lawrence begins to receive water from the Ottawa river. The Ottawa discharges into the lake of Two Mountains, which lies just north of lake St. Louis, and is at a slightly higher level. That lake discharges a part of the flow through two outlets into lake St. Louis and the remainder into the St. Lawrence below Montreal, through two rivers lying to the north of the city. On account of the widely varying flow of the Ottawa, the range in the levels of lake St. Louis is about 8 feet.

181. The winter rise of the river due to the ice gorging raises the water in the La Prairie basin by 10 feet or more.

182. Prior Plans. The improvement proposed for this section in the Report of 1921 was a side canal, 9 miles in length (10 miles to the end of the Lachine breakwater), with two lift locks and one guard lock, extending from the upper entrance to the present Lachine canal across the bend in the river to a point on the shore 3 miles above Montreal harbour (avoiding the built up portion of the city), thence along the shore to the harbour. The eventual increase in depth from the 25 feet provided in that report to 30 feet was to be secured by a dam in the Lachine rapids, which would raise the low-water levels of lake St. Louis and the upper canal level by 5 feet. The report considered, but did not recommend, an alternative project for combining navigation and power by constructing a dam and power works in the Lachine rapids.

183. Plan Recommended by Board. The Board has examined with care the feasibility of utilizing the contracted section of the river above the Lachine rapids for navigation, in connection with power development at these rapids, but finds that, without an excessive amount of costly excavation, the currents created by the concentration of the flow in the excavated channels would be excessive for navigation, even if the railroad bridge which here crosses the river were raised, at large cost, to provide overhead clearance. A side canal affords, therefore, the most suitable route for navigation between Montreal harbour and lake St. Louis.

184. The westward growth of the built up sections of the city of Montreal has already encroached on a part of the route selected for the canal in the Report of 1921. It is highly advisable to build the canal on a location that will not interfere with the future growth of the city and will eliminate the difficult problem inherent to the crossing of land and water traffic with the consequent incon-

venience and delay to both. The route now proposed, therefore, follows close to the river bank throughout and consequently cuts off no area capable of urban development. Its length and its cost are substantially the same as on the route recommended in the Report of 1921. The canal has three lift locks and a guard gate, instead of the two lift locks and the guard lock proposed in that report. But 4 miles are in land cut with minimum section. The remaining 6 miles (counting the length to the end of the Lachine breakwater) have a minimum width of 300 feet. The additional lock assures the minimum alterations in sewerage and water supply systems, including the Montreal aqueduct. When the project is adopted, details can be modified to conform to any projected changes in these public utilities.

185. The excavation of the upper level of the canal, and through the long shoals at the foot of lake St. Louis, can be reduced by the construction of a control dam in the river at the head of the Lachine rapids, above Heron island, to raise the low-water levels of lake St. Louis to elevation 71 during the navigation season. Since at low stages this would back the water up into the lake of Two Mountains and slightly raise also the low-water levels of the latter, it is necessary to construct supplementary control works at the two northerly outlets of that lake (Mille Iles and des Prairies rivers) in order to preserve the present distribution of the flow of the Ottawa, and to prevent a reduction in the flow in the main channel of the St. Lawrence past Montreal. The cost of the entire system of control works is about $2,000,000 in excess of the saving in excavation costs; but these works will reduce the cost of a future development of power at the Lachine rapids, besides being of benefit to local navigation on the two lakes. Their construction is therefore desirable, and is included in the plans of the initial improvement for navigation.

A detailed description of the improvement proposed is given in Appendix C. Its complete cost is estimated at $53,000,000.

186. Power Development. The Board concurs in the views expressed in the Report of 1921 that the feasible power production in this section is limited to the development of the head of a little more than 30 feet available above the foot of the Lachine rapids. The winter rises of the river drown out the remaining head, and the upper level of a power development cannot be carried below the foot of these rapids without causing widespread flood damage.

187. To assure the safe and dependable winter operation of a power development at the Lachine rapids, the discharge capacity of the contracted reaches above these rapids should be so enlarged that the maximum winter current velocities will not create ice gorging. The alternative of a development based on maintaining an open channel through the river in winter is rejected as hazardous for the same reasons that such a proposal is rejected in the International Rapids Section (paragraph 153).

188. The most feasible method of enlarging the discharge capacity of the river is found to be the construction of a deep, concrete-lined headrace canal on the south side of the river. The plans for improving the river for power provide, therefore, for a development in two parts. The first part is the construction of such a power canal along the south shore, from the foot of lake St. Louis to the Lachine rapids, designed to carry a flow of 120,000 cubic feet per second at so high a velocity that an ice cover cannot catch across to form

an ice jam. The water would be delivered to a power house on the south shore at the foot of the rapids, discharging into the La Prairie basin, and would develop 391,000 horse-power.

189. A control dam in the river, with auxiliary structures at the outlets of the lake of Two Mountains, is required with the first part of the development, to prevent the lowering of lake St. Louis by the large diversion, and to secure the maximum allowable head at the power-house. The main control dam in the river would be at the head of the Lachine rapids, at the same location as the dam hereinbefore proposed to regulate the levels of lake St. Louis for the benefit of navigation, and the normal regulated level of the lake would be at elevation 71 in both cases. The auxiliary control structures would be identical. The main control dam would, however, require a different design. The dam proposed in connection with navigation improvement is designed with wide openings to be left clear in winter, in order to prevent the danger of the formation of an ice jam. With the power canal in operation, the currents in the main river would be so reduced as to eliminate the danger of an ice jam, but the openings must be reduced to such dimensions as will afford safe and convenient winter operation of the gates. A dam constructed initially for navigation purposes would therefore require alterations when the first part of the power development is undertaken. The cost of these alterations is estimated at $281,000.

190. The estimated cost of this first part of the development is $88,131,000 if no control dam has been built for navigation purposes, and $81,247,000 if such a dam has been built, the latter figure including the necessary modifications in the dam.

191. The second part of the improvement for power is the development of 422,000 horse-power from the remaining flow of the river, at a power house to be constructed in the main river at the foot of the Lachine rapids, adjacent to the power house constructed in the first part of the development. The headrace to this power house would be formed by a longitudinal wall extending downstream from the control dam previously constructed, to the new power house, and by opening the portion of the control dam between this wall and the south shore. The estimated cost of the second part of the development is $41,966,000.

192. Joint Improvement for Navigation and Power. If the first part of the power development be undertaken simultaneously with the navigation improvement, the estimated combined cost would be $133,358,000.

193. If the first part of the power development be undertaken subsequently to the navigation improvement, requiring the alteration of the control dam initially constructed for the latter purpose, the combined cost would be $134,247,000.

194. The economic saving from combining power development with the improvement of the Lachine Section for navigation is therefore but $889,000, and this saving would be soon counterbalanced by the interest charges on the large investment necessary to secure it, unless the power could be marketed promptly at remunerative rates. For this reason, and on account of the high cost of developing power in this section as compared with its cost in the Soulanges Section, the Board does not include power development in its plans for the intial improvement of this section. The development of power can be undertaken when found economically justifiable from the standpoint of power production alone.

195. In summary, the estimates for this section are as follows:—

Recommended project for navigation alone		$ 53,000,000
Power alone—1st part, 435,000 installed horse-power.	88,131,000	
2nd part, 488,000 installed horse-power.	41,406,000	
Total, 923,000 installed horse-power		$129,537,000
Power subsequent to navigation—		
1st part, 435,000 installed horse-power.	81,247,000	
2nd part, 488,000 installed horse-power.	41,966,000	
Total, 923,000 installed horse-power		$123,213,000

GENERAL SUMMARY

Lake Ontario to Montreal Harbour

196. Improvement Proposed. In summary, the plans recommended by the Board for the improvement of the river will provide to the best advantage for a navigation route through the 183 miles of river and lake from lake Ontario to Montreal harbour, with a total not exceeding 25 miles of restricted canal navigation, and with not more than nine locks. It will be crossed by but eight bridges. The plans include power houses with an ultimate installed capacity of from 2,619,000 to 2,730,000 horse-power, and permit the eventual development with installed capacity of approximately 5,000,000 horse-power which is the full power potentiality of the river.

197. Initial Expenditure Required. The estimated expenditures required to open navigation with channels 25 feet in depth, with an initial power development having one-half the ultimate installed capacity of the power houses first constructed (the installation of the remainder being deferred to await the growth of the market), is as follows:—

(1*a*)	Total cost of improvement if with a single-stage development in the International Rapids Section (1,365,000 horse-power initially installed)	$350,100,000
	or	
(1*b*)	Above improvement before channels are enlarged to ensure winter operation	$337,100,000
	or	
(2)	Total cost of improvement if with a two-stage development in the International Rapids Section (1,365,000 horse-power initially installed)	$385,500,000
	or	
(2*b*)	Above improvement if the initial power installation in the International Rapids Section is all made at the lower (Barnhart island) plant	$361,600,000

198. Cost of Works Complete. After all of the machinery in plants recommended by the Board has been installed, these costs will become respectively:—

(1)	If with a single-stage development of the International Rapids Section (2,730,000 installed horse-power)	$394,000,000
	or	
(2)	If with a two-stage development of the International Rapids Section (2,619,000 installed horse-power)	$423,600,000

199. Alternative Plans. The Board has considered it advisable to present alternative plans and estimates in several instances for the reason that a choice between them rests on broad questions of policy rather than upon strictly engineering considerations.

200. Effect of Channel Depth on Cost. The estimated cost of additional channel excavation required to provide channels initially 27 feet deep from lake Ontario to Montreal instead of 25 feet deep is $5,800,000.

201. The estimated saving in the cost of channel excavation through providing channels initially 23 feet deep instead of 25 feet deep is $5,350,000.

202. The estimated cost of subsequently enlarging to 30 feet depth channels initially excavated 25 feet in depth is $24,400,000.

203. Cost of Additional Works for Full Development of Power. The estimated cost of additional works required to complete the full practicable development of power in the river, with works having an installed capacity of 2,500,000 horse-power is approximately $225,000,000. The total eventual power installation visualized is therefore approximately 5,000,000 horse-power; and the total eventual cost of developing this power, and of providing navigation with channels 25 feet in depth, is in round numbers from $620,000,000 to $650,000,000, depending upon the form of improvement adopted in the International Rapids Section.

204. Analysis of Costs. A general analysis of these costs is shown in the following tables:—

Table I

Recommended Plans with Single-Stage Development in International Power Section

(a)	(b)	(c)	(d)	(e)	(f)	(g)
Section	Cost of works solely for navigation.	Cost of works primarily for power.	Cost of works jointly for power and navigation.	Total cost with complete initial power installation.	Initial cost if one half initial power installation is deferred.	Complete installed capacity of initial works, provided in estimate column (e)
	$	$	$	$	$	h.p.
Thousand Islands......	1,100,000	....	....	1,100,000	1,100,000	....
International Rapids...	22,000,000	106,500,000	106,500,000	235,000,000	203,000,000[1]	2,326,000
Lake St. Francis.......	980,000	....	....	980,000	980,000	....
Soulanges..............	31,594,000	37,665,000	34,686,000	103,945,000	92,000,000	404,300
Lachine................	53,000,000	....	....	53,000,000	53,000,000	....
Total............	108,674,000	144,165,000	141,186,000	394,025,000	350,080,000[1]	2,730,300

[1] Including $13,000,000 for channel enlargement to assure winter operation.

TABLE II

RECOMMENDED plans with Two-Stage Development in International Power Section

(a) Section	(b) Cost of works solely for navigation	(c) Cost of works primarily for power	(d) Cost of works jointly for power and navigation	(e) Total cost with complete initial power installation	(f) Initial cost if one half initial power installation is deferred	(g) Complete installed capacity of initial works provided in estimate column (e)
	$	$	$	$	$	h.p.
Thousand Islands	1,100,000	....	....	1,100,000	1,100,000	....
International Rapids	33,481,000	140,209,000	90,656,000	264,546,000	238,400,000[1]	2,215,000
Lake St. Francis	980,000	....	....	980,000	980,000	....
Soulanges	31,594,000	37,665,000	34,686,000	103,945,000	92,000,000	404,300
Lachine	53,000,000	....	....	53,000,000	53,000,000	....
Total	120,155,000	177,874,000	125,542,000	423,571,000	385,480,000[2]	2,619,300

[1] This becomes $214,500,000 if installation is at Barnhart island powerhouses.
[2] This becomes $361,580,000 if initial installation in International Rapids Section is at Barnhart island powerhouses.

TABLE III

ESTIMATED cost of additional works to complete the full practicable development of power in the river

Section	Installed Horsepower	Cost
	$	$
Soulanges Section—		
First part included in Tables I and II	....	....
Second part	545,000	37,391,000
Third part	1,030,000	63,816,000
Lachine Section—		
First part	435,000	81,247,000
Second part	488,000	41,966,000
Total	2,498,000	224,420,000

TABLE IV

ESTIMATED cost of improving the river for power alone, with power development as provided in the recommended joint navigation and power improvement (14 foot navigation maintained).

Section	With the two-stage development of the International Rapids Section	With the single-stage development of the International Rapids Section
	$	$
International Rapids Section	231,800,000	213,000,000
Soulanges Section	77,172,000	77,172,000
Total	308,972,000	290,172,000

Table V

Estimated cost of improving the river for navigation alone, under the least expensive alternative plan

Thousand Islands Section	1,100,000
International Rapids Section	79,000,000
Lake St. Francis Section	980,000
Soulanges Section	33,640,000
Lachine Section	53,000,000
Total	$167,720,000

Table VI

Tabulated Estimates of cost of providing channels of various depths from the head of the Great Lakes to Montreal, including the installation of 1,365,000 horse-power on the St. Lawrence and the entire cost of the new Welland ship canal.

—	23 feet depth	25 feet depth	27 feet depth	30 feet depth
	$	$	$	$
Great Lakes—				
Connecting channels	....	41,100,000	54,900,000	75,900,000
St. Marys River Locks	....	....	6,500,000	6,500,000
Compensating Works	3,400,000	3,600,000	3,700,000	3,800,000
Welland Canal	114,500,000	114,500,000	115,600,000	128,600,000
St. Lawrence River to Montreal	344,700,000	350,100,000	355,900,000	*374,500,000
	462,600,000	509,300,000	536,600,000	589,300,000

*Based on subsequent deepening from 25 feet.

PART IV

ST. LAWRENCE RIVER AT AND BELOW MONTREAL

205. This part of the report deals with the effect of the diversion of water from the Great Lakes system on the water levels at and below Montreal and with measures for restoring these levels (Question 6). It also considers the effect of the proposed improvement of the St. Lawrence on these levels (Question 5).

DESCRIPTION

206. Montreal harbour is a highly developed port, with 9 miles of improved wharf frontage, grain elevators with a total storage capacity of twelve million bushels, and an extensive warehousing system. The commerce through the port in 1925 amounted to 9,137,281 tons, including 166 million bushels of grain.

The water levels in Montreal harbour during the navigation season range generally between 18 and 28 feet above mean sea-level, depending upon the flow of the St. Lawrence and the Ottawa rivers, the higher stages being due to the spring floods in the Ottawa. In winter, the increased slope of the river due to ice retardation raises the water surface by from 10 to 20 feet, and ice jams occurring during the break-up season in April have raised the water to the stage of 52 feet above mean sea level.

207. The wharves in Montreal harbour are of exceptionally massive construction, to resist damage by ice at the high winter and spring levels. They are built typically with high masonry walls founded on wooden cribbing. The vessel berths at the wharves in the upper portion of the harbour are generally excavated in rock. Extreme low-water levels, which would expose the wooden foundations of the wharves, with consequent danger of decay, are regarded as of serious consequence; and the berths at wharves cannot be deepened readily to meet a reduction in the water levels.

208. Montreal lies 53 statute miles upstream from lake St. Peter, a wide expanse of shallow water, which is the head of the tide in the St. Lawrence. Below the city of Quebec, 160 miles downstream from Montreal, the river is a tidal estuary, with its mean level substantially at mean sea-level. The river below Montreal has been improved by dredging to afford a channel with 450 feet minimum width, 30 feet deep at water levels corresponding to a stage at the head of Montreal harbour, 18.4 feet above mean sea-level (low water of 1897 as modified). The water level rarely falls below this datum. This channel is now under enlargement to 35 feet depth. The expenditures by Canada on the improvement of the channel below Montreal, to March 31, 1925, have been as follows:—

Dredging, field cost	17,434,683 66
Plant, shops, surveys, etc	10,268,461 52
Total	$27,703,145 18

EFFECT OF DIVERSION OF WATER

209. An accurate determination of the relation between the river discharge past Montreal and the river stage is complicated by the fact that these stages are modified by the varying discharge of the tributaries entering the river below Montreal, including the main part of the discharge of the Ottawa, and are affected by the long period tidal fluctuations.

210. A detailed analysis of the relation between gauge heights and discharge, given in Appendix D, shows, however, that a diminution of the flow past Montreal reduces the water levels in the harbour, at the rate of one foot for each 23,000 cubic feet per second of flow. The authorized diversion of 8,500 cubic feet per second through the Chicago Drainage canal reduces the levels in Montreal harbour, therefore, by 0.37 foot. A similar analysis shows the following effects at points below Montreal:—

Locality	Statute miles below Montreal	Amount by which levels are lowered by diversion of 8,500 cfs.
Montreal	0	0·37 foot
Varennes	13	0·35 "
Sorel	45	0·28 "
Batiscan	100	0·24 "
Lotbiniere	117	0·24 "
Platon	125	0·17 "
Quebec	160	0·03 "

RESTORATION OF NAVIGABLE DEPTHS

211. Channel below Montreal Harbour.—The navigable depths of the channels below Montreal harbour can be restored by dredging. An analysis of the gauge records shows that the dredging heretofore done has lowered the levels in Montreal harbour at the rate of 0.15 foot for each foot of navigable depth gained, and has lowered the levels of the river between Varennes and Quebec by an average of 0.06 foot for each foot of navigable depth gained. The estimated cost of increasing the effective depths of the channel below Montreal by the amounts found in the foregoing tabulation, if done as a part of the present project for a general increase in depth, and at the current costs of such dredging, is as follows:—

3,168,000 cubic yards dredging at 42.5 cents per cubic yard	1,346,400
Plant, shops, surveys, etc.—Average proportional cost since beginning of work, 60 per cent	807,600
Total	$2,154,000

212. Montreal Harbour.—The navigable depths in Montreal harbour can be restored by similar dredging. The estimated cost of this dredging necessary to compensate for a diversion of 8,500 cubic feet per second is as follows:—

Shale rock, 87,350 cubic yards at $3.50	305,725
Earth, 289,000 cubic yards at $1	289,000
Engineering and administration, approximately 10 per cent	59,275
Total	$654,000

213. The unit costs are based on the execution of the work as a part of a general project for deepening the harbour. The removal, as a separate undertaking, of the 5-inch layer required to compensate for the diversion would be much more expensive.

214. A comprehensive project for deepening the harbour would, however, require the reconstruction of a large amount of dock wall. An estimate of the part of the cost of reconstruction chargeable to diversion of water obviously presents difficulties. This diversion is but a contributing cause to the need for enlargement, for there has been a loss of 1.15 feet in depth in the harbour since 1895 due to other causes. The older dock walls will require reconstruction in the not distant future on account of deterioration. The Canadian Section of

the Board has prepared an estimate of $1,800,000 as the part of the cost of rebuilding dock walls due to the lowering of the levels by a diversion of 8,500 cubic feet per second, the details of which are set forth in Appendix D. The American Section accepts this estimate with the understanding that it is subject to further investigation and revision.

215. A study was made of the possibility of constructing contraction works in the river below Montreal harbour to compensate for the effect of such a diversion. No substantial saving was indicated by this course.

216. Summary. In summary, the cost of restoring the navigable depths at and below Montreal to the extent that they have been affected by the authorized diversion of 8,500 cubic feet per second is as follows:—

Dredging, Montreal Harbour	654,000
Reconstruction of dock walls, Montreal Harbour	1,800,000
Dredging, below Montreal Harbour	2,154,000
Total	$4,608,000

217. Control Works with Locks below Montreal. The suggestion has been advanced that, instead of securing the desired channel depth at and below Montreal by further dredging, control works with twin locks could be constructed in the river below Montreal to raise the water levels to the extent required for that purpose. Such a structure must be so designed that it would not aggravate ice conditions in winter, and therefore would be costly. It would afford incidentally a complete remedy for the lowering of the water in Montreal Harbour due both to channel enlargement and to the diversion of water, and also would afford an opportunity for the fuller development of power, especially in the Lachine Section, since the restrictions as to maintaining uniformity of flow could be made less stringent. The consideration of such a scheme is beyond the scope of the instructions to the Board.

EFFECT OF PROPOSED IMPROVEMENT OF THE ST. LAWRENCE RIVER

218. The improvement of the St. Lawrence river could affect the water levels at and below Montreal to the extent only that the works might be so operated as to modify the rate of discharge of water down the river. The program for the regulation of lake Ontario recommended by the Board (Appendix B) is so drawn as to afford mean discharges during the critical months of September, October and November at least equal to the discharges that occur in nature; and discharges in the first half of April, when the river has its maximum flood levels, no greater than those that would occur with equal frequency without regulation. There remains the possibility of the introduction of fluctuations in the discharge of the river through the fluctuations in the discharges through the power plants to meet their changing loads.

219. Any necessary uniformity of discharge past the various power structures can be secured by opening sluice gates as the power load and power house discharge diminishes. Power can be profitably generated at the various plants recommended by the Board without causing any greater hourly and daily fluctuations in the water levels at Montreal than now occur from natural causes, and suitable government supervision, both over the plants in the International Section and over those in the province of Quebec, can assure this result.

220. In short, all the works of the improvement of the St. Lawrence river must be so operated as to have no injurious effect on the water levels at and below Montreal.

PART V

FINDINGS ON QUESTIONS CONTAINED IN THE INSTRUCTIONS TO THE JOINT BOARD OF ENGINEERS

221. Answering specifically the questions contained in its instructions, the Board finds:—

Question 1

" Is the scheme for the improvement of the St. Lawrence waterway, presented by the board in its report of June 24, 1921 (herein referred to as the Report of 1921), practicable and does it provide to the best advantage, at this time and ultimately, for the development of the capacities and possibilities of the waterway?"

222. Answer. The scheme as presented in the Report of 1921 is, in its broad lines, practicable; but should in the opinion of this Board be modified to provide to the best present advantage, at this time and ultimately, for the development of the capacities and possibilities of the waterway.

Question 2

" What alternative scheme, if any, would be better adapted to secure the ends desired, due consideration being given,—

" (*a*) To any special international or local interests having an importance justifying exceptional consideration; and

" (*b*) To the extent and character of the damage through flooding and the probable effect of the works upon the formation of ice and the consequent effect on the flow of the river?"

223. Answer. The plans recommended by the present Board are set forth in Part III of this report, and are described in detail in Appendix C.

224. The plans presented in the Report of 1921 are altered in their broader features as follows:—

225. In the International Rapids Section (Fourth Division of the Report of 1921) the plans now presented provide for the development of the entire power possibilities of the section, without subsequent alterations in the works. Two alternative schemes for accomplishing this result are presented, one for a two-stage development, the other for a single-stage development.

226. In the Soulanges Section (Second Division) the Board recommends a scheme for navigation correlated with a progressive development of power instead of a side canal for navigation only.

227. In the Lachine Section (First Division) the alignment of the navigation canal is changed to secure a minimum interference between land and water traffic, and a control dam to regulate the levels of lake St. Louis has been included in the initial development.

228. The plans proposed have been drawn with full regard to all interests concerned. Flowage damage is inseparable from a practicable development of power on the St. Lawrence, since freedom from floods has led to the occupation

of its banks almost to the waters edge. The plans have been drawn to reduce to a minimum the flowage consequent to the plans proposed. They have been prepared with special care to meet ice conditions affecting the flow of the river.

Question 3

"Should the estimates of cost be revised, and, if so, what are the revised estimates of cost having regard to alternative schemes?"

229. Answer. The estimates should be revised. The estimates of the works proposed by this Board, with hydro-electric machinery completely installed, exclusive of interest during construction, are as follows:—

(1) If a single-stage development be adopted in International Rapids Section—

Works solely for navigation	108,700,000
Works common to power and navigation	141,200,000
Works primarily for power	144,100,000
Total	$394,000,000

Installed capacity 2,730,300 horse-power.

(2) If a two-stage development be adopted in International Rapids Section—

Works solely for navigation	120,200,000
Works common to power and navigation	125,500,000
Works primarily for power	177,900,000
Total	$423,600,000

Installed capacity 2,619,000 horse-power.

230. The Board considers that sound business management will dictate the initial installation of but a part of the hydro-electric machinery with its housing and accessories. With a total initial installation of 1,368,000 horse-power, the initial costs, including all features required for navigation and with complete channel enlargement for winter power operation, becomes respectively $350,100,-000 and $385,500,000.

231. The plans presented by the Board outline a subsequent complete development of the power resources of the river, by the construction of additional power works with an installed capacity of approximately 2,500,000 horse-power, at an additional cost of approximately $225,000,000.

232. The total ultimate development visualized on the St. Lawrence river by the Board amounts therefore to approximately 5,000,000 horse-power at a total cost of from $620,000,000 to $650,000,000, including navigation works. Further details of estimates are given in Part III, paragraphs 200 to 204.

Question 4

"In order to assist either Government to allocate the amounts chargeable to navigation and power, what would be the respective estimated costs for improving the river for navigation alone and for power alone?"

233. Answer. The estimated costs for the initial improvement of each river section, (*a*) on plans recommended by the Board for both power and navigation, (*b*) on similar plans for the development of the same amount of power without any navigation works other than to maintain the existing 14-foot navigation, and (*c*) on alternative plans for practicable, though inferior, navigation through the power sections, are shown in parallel columns as follows:—

(1) If a single-stage development is adopted in the International Power section—

Section	(a) Plans recommended	(b) Power alone	(c) Navigation alone
Upper International	1,100,000	....	1,100,000
International power	235,000,000	213,000,000	79,000,000
Lake St. Francis	980,000	....	980,000
Soulanges	103,945,000	77,172,000	33,640,000
Lachine	53,000,000	....	53,000,000
Total	$394,025,000	$290,172,000	$167,720,000

(2) If a two-stage development is adopted in the International Power Section—

Section	(a) Plans Recommended	(b) Power alone	(c) Navigation alone
Upper International	1,100,000	....	1,100,000
International power	264,546,000	231,800,000	79,000,000
Lake St. Francis	980,000	....	980,000
Soulanges	103,945,000	77,172,000	33,640,000
Lachine	53,000,000	....	53,000,000
Total	$423,571,000	$308,972,000	$167,720,000

Question 5

"To what extent may water levels in the St. Lawrence River at and below Montreal, as well as the river and lake levels generally, be affected by the execution of the project?"

234. Answer. The irresponsible operation of the power works proposed by the Board, or indeed of any power works, however designed, that develop fully the power resources of any section of the river, would affect injuriously the water levels in the St. Lawrence river at and below Montreal; but it is feasible to operate these works under Government supervision in such manner that they will neither lower the summer levels in the lower river nor raise the winter and spring levels. With such control the improvements proposed will have no injurious effect whatever on the water levels of the St. Lawrence at and below Montreal.

235. The high levels on lake Ontario, of the upper reaches of the St. Lawrence river, extending 67 miles from that lake, and of lake St. Francis and lake St. Louis, will not be raised by the improvement. The low levels of lake Ontario and of these upper reaches of the St. Lawrence will not be made lower. The low levels of lake St. Francis will be raised about a foot and of lake St. Louis about 5 feet. The dams proposed in the power reaches of the St. Lawrence will create material local changes in the levels of these reaches only.

236. The levels of the Great Lakes above lake Ontario cannot be affected by any works in the St. Lawrence proper. Works to restore the effects of channel enlargement and of diversions from lakes above lake Ontario, are dealt with under the replies to Question 6 (b) and 10.

Question 6 (*a*)

"To what extent and in what manner are the natural water levels in the St. Lawrence river and on the lakes affected by diversions authorized by license by either Canada or the United States, from or in the St. Lawrence river watershed?"

237. Answer. The diversion by the Chicago Sanitary District of 8,500 cubic feet per second from the lake basin through the Chicago Drainage canal, authorized by license by the United States, lowers the water levels on the Great Lakes and the St. Lawrence river as follows:—

Lakes Michigan and Huron	0.5 foot
Lake Erie	0.4 foot
Lake Ontario	0.4 foot
St Lawrence river between lake Ontario and Montreal—	
At Prescott	0.4 foot
At Lock 25 (Iroquois)	0.6 foot
At Lock 23 (Morrisburg)	0.5 foot
At Lock 21 (Dickensons Landing)	0.4 foot
At Lock 15 (Cornwall)	0.3 foot
Lake St. Francis	0.2 foot
Lake St. Louis	0.3 foot
St. Lawrence river at and below Montreal—	
At Montreal harbour	0.37 foot
At Varennes	0.35 foot
At Sorel	0.28 foot
At Batiscan	0.24 foot
At Lotbiniere	0.24 foot
At Platon	0.17 foot
At Quebec	0.03 foot

238. The diversion of 2,080 cubic feet per second from lake Erie via the Welland canal for power use by corporations and municipalities authorized by license by Canada lowers the levels of the Great Lakes as follows:—

Lakes Michigan and Huron	0.025 foot
Lake Erie	0.1 foot

239. The foregoing are the only authorized diversions found by the Board to affect appreciably the levels of the lakes and the St. Lawrence. The effect of all diversions, including those for navigation purposes, and of other factors, is described in Part II of this report.

Question 6(*b*)

"By what measures could the water levels of navigable depths affected by the diversions referred to in section 6(*a*) be restored, and what would be the cost thereof?"

240. Answer. The water levels of lakes Michigan, Huron and Erie can be restored most advantageously by compensating works in the St. Clair and Niagara rivers, which should, however, be so designed as to offset all existing diversions and outlet enlargements, as well as the diversions authorized by license. The total cost of these works is estimated at $3,400,000. The cost of similar but less extensive works designed to restore the effect of authorized diversions only, is estimated as follows:—

Diversion compensated for—	Cost of Works
Chicago diversion	$1,750,000
Power diversions, Welland canal	$ 100,000

241. The effect of the diversions on the levels of lake Ontario and of the St. Lawrence river above Montreal will be removed by the works provided for the improvement of this part of the St. Lawrence.

242. The effect of the authorized diversions on the levels of the St. Lawrence river at and below Montreal can be restored by dredging and accessory works at estimated costs as follows:—

Dredging Montreal harbour	654,000
Reconstruction of dock walls, Montreal harbour	1,800,000
Dredging below Montreal	2,154,000
Total	$4,608,000

Question 6(*c*)

"How much power could be developed on the St. Lawrence river with the water diverted from the watershed referred to in section 6(*a*) under—

(1) The plans recommended?

(2) Alternative plans providing for a full practicable development of the river?"

243. Answer. The following amounts of 24-hour power could be developed on the St. Lawrence river with the authorized diversion of 8,500 cubic feet per second from the water shed through the Chicago Drainage canal:—

(1) At the average heads available at the power plants initially recommended—

	Horse-power
In the International Power Section (82.5 feet average head)..	70,125
In the Soulanges Section (22 feet average head)...........	18,700
Total	88,875

(2) At the average heads available at the power plant recommended for the eventual full practicable development of the river—

	Horse-power
In the International Power Section (82.5 feet average head)..	70,125
In the Soulanges Section (75 feet average head).............	63,750
In the Lachine Section (32 feet average head)...............	27,200
Total	161,075

Question 6(*d*)

"Without considering compensation by the present relative diversions of water from the Niagara river and from lake Erie, and without prejudice to a future consideration thereof, what works, if any, could be constructed to recover on the St. Lawrence river the amounts of power determined under section 6(*c*), and what would be the cost of such works?"

244. Answer. The Board finds that after the St. Lawrence river has been fully developed for power production, no works can be constructed which would recover on the St. Lawrence the power lost by the diversion of water from the watershed.

Question 7

"Having regard to economy of construction and maintenance, expedition of construction, and efficiency of operation——

"(*a*) Which of the works should be constructed under the technical supervision of an international board and what other works, if any, might advantageously be constructed under such supervision?

"(b) Which of the works should be maintained and operated by an international board and what other works, if any, might advantageously be so maintained and operated?"

245. Answer (*a*) Construction of Works. All dams, embankments, power house substructures, water-passages, gates and channel enlargements within the International Sections should be designed and constructed under the technical supervision of a single international authority.

246. The purpose of this is to make sure that the different parts of the works will not be so prosecuted as to interfere with each other, and that safe and equitable regulation of both winter and summer flows of the river will be possible

both during and after construction; as well as to secure uniformity, economy and expedition by co-ordinating design and construction programs.

247. The same authority should co-ordinate for the entire river, from lake Ontario to Montreal, the programs of construction and the channel dimensions and clearances for works necessary to secure through navigation.

248. (*b*) Maintenance and Operation of Works. The Board regards it as essential that an international control board be created with full power to regulate the use of water at the power plants in the International Section in order that such use may be prevented from creating conditions harmful to navigation in any part of the St. Lawrence, and in order that the operation of the various power plants be conducted with full regard to the use of water at other power plants on the river.

All locks and other navigation structures will necessarily lie in the territory of one country or the other, and can be most advantageously maintained and operated by the usual government agencies of the two countries.

Question 8

> "What, if any, readjustments in the location of the international boundary are necessary or desirable to place power structures belonging to either country within its borders, as recommended by the International Joint Commission?"

249. Answer. Readjustments in the international boundary are necessary only in the International Rapids Section and depend upon the plan adopted for the improvement of that section.

A change in the boundary in the vicinity of Barnhart island is necessary irrespective of whether the single-stage or the two-stage scheme be adopted in this Section. If, with either of these general schemes, the dam is located at the foot of Long Sault island and both powerhouses at the foot of Barnhart island, as shown on the plans of the two-stage development, a change is necessary between Turning Points 10 and 14 to bring the power houses within the borders of the two countries. If, on the other hand, the dam and power houses are at the foot of Barnhart island, with the United States power house on the mainland of the United States, as shown on the plans of the single stage development, it is desirable to so change the boundary between Turning Points 10 and 21 as to bring all of Barnhart island into Canadian territory. This island is separated from other American territory by the main channel of the St. Lawrence. The estimates include the acquisition of the entire island in connection with power development, and the land remaining unsubmerged can, with this plan, be put to beneficial use only in connection with the Canadian power house located thereon.

250. With the two-stage scheme, a slight change is needed also in the boundary north of Ogden island, to bring the power houses at that locality within the borders of the respective countries.

251. A detailed description of the necessary changes will be given in Appendix C.

Question 9

> "If the Board is of the opinion that it would be advantageous to provide in the first instance for channel depths other than 25 feet, but less than 30 feet, for what draft of vessel should provision be made?"—

252. Answer. As explained in paragraph 111, Part III, the Board is not agreed on the advantage of any depth other than 25 feet.

QUESTION 10

"Having regard to the recommendation of the International Joint Commission that the new Welland ship canal should be embodied in the scheme and should be treated as a part thereof, and to the fact that if a greater depth than 21 feet be adopted for the initial project depth of the St. Lawrence, such greater depth would not be available to the upper lake ports without further work in the navigation channels in the Lakes, what would be the cost of improving the main navigation channels between and through the lakes, so as to provide, without impairing the present lake levels, for (*a*) a depth of 25 feet and (*b*) for such other depth not exceeding 30 feet, as may be determined by the Board to be that for which it would be most advantageous to provide on the St. Lawrence river?"

253. ANSWER. The cost of improving the main navigation channels between and through the lakes, so as to provide a depth of 25 feet, including all compensating works constructed in furtherance of the work, is estimated at $44,700,000, not including the cost of the new Welland ship canal.

QUESTION 11

"What is the time required to complete the proposed works, the order in which they should be proceeded with, and the progress which should be made yearly toward the completion of each in order to secure the greatest advantage from each of the works and from the development of the waterway as a whole?"

254. ANSWER. It is estimated that the waterway can be opened to navigation in from seven to eight years from the time that active work has been begun. All works should be so prosecuted as to insure the completion of navigation works at the same time. A complete program for the prosecution of the work will be presented in Appendix G.

APPENDICES

255. The investigations by the Board are set forth more fully in appendices as follows:—

Appendix A—Field investigations.
" B—Lake levels and outflows.
" C—Detailed plans and estimates for the improvement of the St. Lawrence.
" D—River levels and discharges at and below Montreal.
" E—Ice formation on St. Lawrence.
" F—Experiments on strength of ice.
" G—Construction program.

United States Section	*Canadian Section*
EDGAR JADWIN, *Major General, Chief of Engineers.*	DUNCAN W. McLACHLAN,
WILLIAM KELLY, *Colonel, Corps of Engineers.*	OLIVIER O. LEFEBVRE,
G. B. PILLSBURY, *Lieut. Colonel, Corps of Engineers.*	CHARLES HAMILTON MITCHELL.

WASHINGTON, D.C., November 16, 1926.

ST. LAWRENCE WATERWAY PROJECT

Memorandum *re* Appendices to accompany Report of Joint Board of Engineers

Since the completion of the Main Report dated November 16, 1926, the Board has completed Appendices as follows:—

Appendix A—Field Investigations
" B—Lake Levels and Out Flows
" C—Detail plans, and estimates of Projects
" D—River levels and discharges at and below Montreal
" E—Ice formation on the St. Lawrence
" F—Experiments on the Strength of ice
" G—Construction program

In these Appendices alternatives are presented to those described in the main report. Attention is invited to the Crysler Island two-stage project presented by the Canadian Section for the International Rapids Section. This project is described in paragraphs 121 to 134 of Appendix C.

United States Section:

EDGAR JADWIN,
Major General, Chief of Engineers.

WILLIAM KELLY,
Colonel, Corps of Engineers.

G. B. PILLSBURY,
Lieutenant Colonel, Corps of Engineers.

Canadian Section:

DUNCAN W. McLACHLAN.

OLIVIER O. LEFEBVRE.

CHARLES H. MITCHELL.

DETROIT, MICHIGAN, July 13, 1927.

APPENDIX A

FIELD AND OFFICE INVESTIGATIONS

INVESTIGATIONS BY CANADIAN SECTION

1. The Canadian Section of the Board was appointed on May 7, 1924. On that date funds were available for the work. A central office was etsablished in Ottawa and an organization was already in the field. After May, 1924, the personnel in both field and office was increased and work was prosecuted with energy from that time until the end of 1926.

2. Staff. Throughout the progress of investigations a field office was maintained at Cornwall. Mr. Russell Yuill, B.Sc., was in local charge of this office and also directed all boring and survey parties at work in the field.

3. Mr. Guy A. Lindsay, B.Sc., supervised the preparation of detail plans and estimates in Ottawa as well as the greater part of the hydraulic computations made.

4. Mr. J. K. Wyman, B.Sc., developed stage relation diagrams for the St. Lawrence above and below Montreal and determined the effect of outlet changes at a number of critical points in the Great Lakes System. He developed a number of schemes for regulation of the Great Lakes, including that of Lake Ontario.

5. Mr. A. L. Mudge, B.Sc., had charge of the assembly and preparation of tentative lay-out plans for power houses and the assembly of data obtained from manufacturers of hydraulic and electrical machinery.

6. Mr. W. Chase Thomson, M.E.I.C., prepared outline plans and detail estimates for a large number of bridges at various points on the river. Other members of the staff of the Canadian Section did much useful work in connection with the compilation of data, the working out of designs, and the preparation of estimates.

7. Mr. D. W. McLachlan, B.Sc., Chairman of the Canadian Section, was in general charge of all investigations made by the Canadian Section.

8. Borings. A very important part of the work done by the Canadian Section was the borings made to determine the character of foundations.

9. Previous to the appointment of this Board, but subsequent to the filing of the report of 1921, the Canadian Government put down 63 borings, in the years 1922 and 1923. Almost all of these were in the International Section of the river.

10. During the year 1924, the Canadian Section put down 15 borings in the International Section and 15 in the Lachine Section.

11. For drilling in deep swift water, one strong spud scow was built at Cornwall and a lighter spud scow for drilling in quiet water was rented in the spring of 1925. The first scow was equipped with a churn drill and with a Calyx core drill and the second scow was equipped with a churn drill only. These two outfits were put to work in the Canadian Section of the river early in the summer of 1925, and worked continuously during the open season of 1925. They did much difficult work in that season in the Cedars and Lachine

rapids. The rented scow was not used during 1926, but the specially built scow was also used throughout that season, part of the time by the United States Section in the deep swift waters at the foot of Barnhart island.

12. In the years 1925 and 1926, taken together, 22 borings to rock were put down in the International Section and 144 in the part of the river below lake St. Francis. In 1927, 8 borings were put down in the International Section.

13. The number of borings made in the Soulanges Section was 88. Of this number, 17 were along the north shore of the river between Coteau and Cascades, 14 along the south shore of the river between Clark island and St. Timothee, 25 were along the route of a canal between Hungry Bay and Melocheville, 12 were in the river at Cedars, 17 in the Ottawa arm of lake St. Louis, and 3 in Hungry bay.

14. The number of borings put down in the Lachine Section in 1925-26 was 51. Of these, 13 were at the foot of Lake St. Louis, 16 in the LaPrairie Basin, 18 along the north shore of the river between the town of Lachine and the shore of the river at Verdun, and 4 were on the south shore of the river above Lachine rapids.

15. In 1926, 5 borings to rock were made by the Canadian Section in the St. Lawrence river below Montreal.

16. In 1924 and 1925, the Hydro-Electric Power Commission of Ontario put down 128 borings in the International Section of the St. Lawrence.

17. A large number of cores were obtained in connection with the borings made. The cores obtained by the Canadian Section are being preserved at Cornwall for future reference. In almost all cases in which borings were made, solid rock was penetrated a distance of from 10 to 15 feet in order to make sure that a boulder was not mistaken for solid rock. Wash boring equipment was used only in a very few cases by the Canadian Section.

18. The following summary shows the linear feet of borings made by the Canadian Section in 1924, 1925, 1926, and 1927:—

Section	Borings made	Length in earth	Length in rock		Total length
			Uncored	Cored	
		ft.	ft.	ft.	ft.
Below Montreal	5	218	4	24	246
Lachine	66	1,370	1,168	....	2,538
Soulanges	88	1,922	320	127	2,369
International Rapids	45	1,954	409	187	2,550

19. A detailed description of the material penetrated in each hole is on file in the Department of Railways and Canals at Ottawa. The rock elevations found and the location of all borings made are shown in the plans accompanying Appendix "C".

20. Surveys. In the summer of 1924, the surveying of an uncharted portion of the St. Lawrence river, between the town of Lachine and the foot of the Lachine rapids, was undertaken and partially completed. This work was originally plotted at a scale of 400 feet to 1 inch.

21. In the years 1925-26, contour surveys of all islands in the river between lake St. Francis and Montreal were made. Topographical information formerly obtained along the river in the Soulanges Section was greatly extended, particularly on the north shore between lake St. Francis and lake St. Louis.

22. In the Soulanges Section a number of water level profiles were made on both shores of the river and around the larger islands.

23. In a number of cases in this section, basic data from plans of power companies was secured and replotted so that the plans filed with this report show all the data extant in the section.

24. During 1925-26, the surveys of Lachine rapids and LaPrairie basin, begun in 1924, were completed, and topographical information formally derived was extended on both shores of the river so that all areas of interest to the St. Lawrence project were covered.

25. Detail plans showing all buildings and improvements in the village of Caughnawaga and in the highly developed territory between the town of Lachine and Verdun were prepared.

26. In the International Section of the St. Lawrence river, a number of small surveys were made by the staff of the Canadian Section. These embraced the south shore of the river between Lotus island and Iroquois point, the high portions of Ogden island, the lower part of the channel south of Long Sault island, the river bed in the Little Long Sault rapids, and a series of summer cross-sections of the river between Morrisburg and the Long Sault rapids.

27. A comprehensive valuation of all property and buildings affected by the proposed improvements on the Canadian side of the International Section, and in the Long Sault and Lachine Sections, was made in 1926.

28. Temperature Measurements.—In the autumn months of 1924, an elaborate series of water temperature measurements between lake Ontario and lake St. Louis were undertaken. This investigation extended through the early months of winter and furnished much needed data upon heat transfer between water and air in cold weather.

29. A series of water temperature measurements in the Ottawa river, between Grenville and the head of lake St. Louis, were completed during the month of November, 1924.

30. Investigation of Ice Jams and Packs. During 1925, a careful survey of the hanging dams at the head of lake St. Louis was made, and the progress of the ice packs as they built up from the foot of lake St. Peter to Montreal and from the head of lake St. Francis to the Long Sault rapids, was carefully recorded.

31. At the request of the Board, a special survey of an unusual ice jam in the Niagara river was made in the winter of 1924-25, by the staff of the Welland Ship Canal.

32. During the winter of 1924-25 and the two succeeding winters, record was kept of the movements of various ice jams and packs as they occurred at many points in the St. Lawrence river, between the foot of lake Ontario and the head of lake St. Peter.

33. Experiment on Strength of Ice. In the winter of 1925-26, the use of two rooms in the refrigeration plant of the Harbour Commission of Montreal was secured and in these rooms a great many tests of the strength of ice were made. The information obtained from these tests is given in appendix "F".

34. Discharge Measurements. During the open water period of 1924, and again in 1925, many meterings of the St. Lawrence were made above Iroquois Point. During the winter of 1925, careful measurements of the flow

of the river at the head of lake St. Francis were made. These, along with measurements made in the winter of 1923 and 1924, and data compiled by the United States Lake Survey, enabled a close determination of flow out of lake Ontario to be made both for winter and for summer.

35. In addition to meterings mentioned above Iroquois Point, measurements of river flow were also made opposite the mouth of the Montreal Acqueduct, at Boucherville island, and at Vercheres island, and also on the Richelieu, Ottawa, St. Regis and Raquette rivers.

INVESTIGATIONS BY UNITED STATES SECTION

36. The United States Section established a field office at Ogdensburg, N.Y., continuing from April, 1925, to January, 1926. Lieut. Joseph H. Stevenson, Corps of Engineers was in charge to July, 1925, when Col. C. W. Sturtevant assumed charge. Mr. F. W. Maltby was later engaged to collaborate with Col. Sturtevant on the studies of the proposed works.

37. Designs and Estimates. Extensive studies of hydro-electric development in the International Rapids Section were made for the United States Section of the Board by the firm of Viele, Blackwell and Buck, engaged as consulting engineers on this feature of the improvement. Designs and estimates for various schemes for improving the International Sections of the river were prepared by a special force organized in the United States Lake Survey Office at Detroit, in the winter of 1925-26, under Mr. Roger B. McWhorter.

38. Survey, Clayton to Brockville. All shoal areas in this critical section of the proposed navigation route through the upper St. Lawrence were determined by sweeping with a wire drag, set at a depth of at least 33 feet. The work followed the sweeping methods developed by the United States Lake Survey, and was done by a party from the Survey. All shoal spots were sounded at 50 feet intervals. The areas swept, and the shoals found, are shown on the maps accompanying appendix "C". The detailed soundings of the shoal areas are on file in the United States Lake Survey.

39. Probings of the shoal spots were made with a steel rod in the course of the survey, and showed that these were principally solid rock (granite) or boulders.

40. Survey, Chimney Point to Cardinal. On account of the great importance of this section of the river in all plans for improvement, a detailed hydrographic survey of this territory was made and plotted on a scale of 400 feet to the inch.

41. Survey, Barnhart Island. A new detailed hydrographic survey was made from Robinsons' bay to Massena point, and was also plotted on a scale of 400 feet to the inch.

42. Borings. Under a contract entered into with Clarke Brothers, Maysville, Kentucky, 93 wash borings were made to determine the character of the material between Chimney point and Point Three points, in the upper part of the river, and 61 borings, most of which were cored, were made to determine the elevation of suitable foundations for power houses, locks, etc., at the foot of Barnhart island, near the mouth of the Grass river, and at other points. In addition, 28 holes were drilled in this region with rented drills and on a footage basis.

43. To determine the elevation of the rock at the dam site near the foot of the Long Sault rapids, supplementing the special investigations by test pits and horizontal borings later described, a rented diamond drill, mounted on scow, was placed with some difficulty on the mid-channel shoal at the locality, and 5 vertical holes were drilled into rock. The rock elevation at the abutments of a dam at this site were explored by 8 diamond drill borings.

44. It was found that the wash borings made under contract in the upper portion of the river did not afford a reliable indication of the quantity of ledge rock to be handled in the execution of the proposed improvement, and the critical areas were therefore re-examined with diamond and heavy well-drills. These further investigations showed that ledge rock lies, at a number of places, at considerably lower elevations than was indicated by the wash borings above described or those made by the Deep Waterways Board in 1898 and 1899. A few wash borings were also made in the Lake St. Francis Section.

45. Most of the boring operations were made during 1925, but a few supplementary borings were made in 1926 to establish the foundation conditions at sites for structures developed by the office studies. The Canadian Section put its drill barge at the disposal of the United States Section for exploring the proposed dam site near the foot of Barnhart island during the latter season.

46. The following is a summary of the borings made:—

Class	Number	Total length
Borings cored into rock (total length cored approximately 1,100 feet)	102	5,285
Well drill borings	24	1,283
Other borings—		
Reaching desired grade	21	579
Not reaching desired grade	96	1,600
Total	243	8,767

47. The location of the various borings, except such wash borings as were rejected, is shown on the detailed maps accompanying Appendix "C". A detailed description of the borings is on file in the office of the United States Lake Survey at Detroit.

48. Special Exploration of the Dam Site at Long Sault Rapids. At this site, the river flows in two channels on either side of a midstream bar. The swift currents and heavy breaking swells in these channels render ordinary boring inordinately expensive, if not impossible. A test shaft was therefore sunk on the shore on each side, on Barnhart and Long Sault islands respectively, and horizontal borings driven under the river from the bottom of these shafts. As previously described, vertical borings were made on the bar with a diamond drill.

49. Barnhart Island Shaft. The Barnhart island shaft was located on a bench about thirty-five feet above the river surface, and 100 feet from the water's edge. Active work on sinking the shaft was begun July 15, 1925. The collar was set at elevation 210. A timbered shaft was carried to bed rock, which was reached July 25, at elevation 148. The shaft was continued, without timbering, to elevation 121. A sump, with a depth of nine feet, was then excavated and the whole was completed on September 9, 1925.

50. The material penetrated was as follows:—

Elevations	Description of Material
210 to 207	Heavy black loam.
207 to 206·5	Coarse sand.
206·5 to 205·5	Sand and loam.
205·5 to 173	Bluish clay and sand with small rock mixed, turning to a hardpan towards the end.
173 to 150	Shale hardpan. This material was very hard, requiring shooting to loosen it up. It seemed to lay in layers and while it could be picked, much better progress was made by light charges of 40 per cent powder.
150 to 148·5	Blue limestone with large amount of fossils showing. Sloped about 1 to 12 to the south and varied in thickness from 12″ to 18″.
148·5 to 148	Hardpan with excess sand.
148 to 145	Blue limestone with seams ¼″ to 1″ thick of pure sand running both horizontally and vertical.
145 to 138·5	Blue limestone. Very hard with tight seams running both vertical and horizontal. Shatters easily under 60 per cent powder. There was a small open seam at elevation 141.
138·5	Seam 3″ thick of soft shale laying almost level and extending clear across the hole.
138·2 to 125	Hard blue limestone.
125 to 121	Blue limestone but softer and showing large amount of fossils. Lighter in color.
121 to bottom of sump, approx. 112	Hard blue limestone.

51. The work was done by hired labour and was under the supervision of Junior Engineer W. B. Anthony.

52. Long Sault Island Shaft. This shaft was located at the foot of Long Sault island, on the shore, about seventy-five feet from the water's edge. Sinking operations commenced on August 13, 1925, and were completed on September 20. The collar of the shaft was placed at elevation 183.6. The timbering was carried down from the surface and was bedded at elevation 159.2 on a limestone stratum.

53. It was found that this limestone stratum was about ten inches thick, underlain by a four-foot layer of shale and separated therefrom by an open seam. When this seam was penetrated, the flow of water produced in the drill hole indicated that the pumping equipment would be insufficient to handle the water if the seam was fully opened. Grouting was therefore resorted to, and the shaft was then successfully completed.

54. The material penetrated was as follows:—

From elevation	To elevation	Description
180·9	171·6	River gravel and sand.
171·6	162·1	Grayish, fine-grained marine clay, containing considerable fine sand.
167·0	162·1	Bluish-gray, thick-bedded limestone.
		NOTE.—This formation was encountered on the west side of the shaft and extended about one-quarter of the way across the shaft.
162·1	161·15	Bluish-gray, fossiliferous limestone.
161·15	159·25	Bluish-gray shale.
159·25	158·45	Bluish-gray limestone.
158·45	154·15	Bluish-gray shale. The contact between this shale and the overlying limestone stratum is an open water seam and was grouted as described above. It is thought that there is a change in the rock series at this contact.
154·15	151·5	Bluish-gray, shaly, fossiliferous limestone.
151·5	147·6	Bluish-gray, fossiliferous limestone.
147·6	145·2	Light bluish-gray, crystalline limestone with shale partings.
145·2	143·1	Bluish-gray, fossiliferous limestone.
143·1	141·7	Bluish-gray, arenaceous limestone.
141·7	138·7	Bluish-gray, crystalline limestone, with shale partings.
138·7	135·9	Light-gray, dense, crystalline limestone with shale partings.
135·9	133·9	Bluish-gray, cross-bedded, shaly limestone.
133·9	131·5	Gray, dense crystalline limestone.
131·6	131·2	Bluish-gray, crystalline limestone, with shale partings.
131·2	128·3	Dove-colored, dense, crystalline limestone.
128·3	126·8	Bluish-gray, coarse, crystalline limestone.
126·8	123·5	Bluish-gray, coarse, crystalline, cross-bedded limestone with shale partings, with quartz deposition on joint planes.
123·5	122·8	Bluish-gray, cross-bedded, finely crystalline limestone with shale partings.
122·8	122·7	Same as No. 21, but lower shale partings.
122·7	119·6	Bluish-gray, dense, crystalline limestone.

55. The work was done by hired labour, three shifts being employed. Mr. W. W. Gruber, Junior Engineer, was in local charge of the work during the period of organization and preliminary construction. Mr. E. L. Lull, Junior Engineer, was in local charge during the sinking of the shaft.

56. HORIZONTAL BORINGS. The horizontal borings were driven under contract with the Pennsylvania Drilling Co., by diamond drills from chambers excavated near the bottom of the shaft. The deflection of the holes from the horizontal was measured every 100 feet by means of etching solution on glass tubes inserted in the holes; and the deflection in direction by compass needle in a congealing solution. It was found that all holes tended to dip downward. The boring from the Long Sault Shaft was driven 690.7 feet with a total calculated downward deflection of 15.7 feet. The first hole driven from the Barnhart Island shaft, when it had penetrated 660 feet, had such a downward inclination that it was apparent that further information from this hole would have little value. A second hole was started with an upward inclination of 1½ per cent. This hole also dipped downward to such an extent that, at the end of 350 feet, it was deemed desirable to discontinue it. A third hole was started with an upward inclination of 3 per cent, and reached a distance of 760 feet, with the elevation at the end of the hole 4 feet below the point of starting. The end of the hole was then approximately 600 feet from proved rock established by a drilled hole on the midstream bar.

57. The material penetrated by all horizontal borings was limestone bedded horizontally, with tight shale seams. No evidence of vertical seams or cavities was shown by any of the holes, and the leakage from all holes was insignificant.

SYNOPSIS OF GEOLOGICAL AND BORING INFORMATION

58. As previously described, various borings, down to and into rock, have been carried out by both sections, distributed throughout the entire length of the river under investigation.

59. In this appendix, it is thought desirable to outline more in detail the nature of the several rock formations and their over-burden, and at the same time to include some typical records of rock borings to indicate the character and arrangement of the strata of the various materials encountered in the more critical localities. These typical records have been selected from those on file in the respective government offices at Ottawa and Detroit.

60. The country rock, apart from the river influences, displays characteristics, including striations, indicating a southerly passage of glaciers. There are in addition, indications of pre-glacial erosion and definite channels which cut across the glacier tracks in an easterly direction, not easy to trace or connect with any definite system. There are repeated series of ridges and valleys in the rock surface, cutting southerly across the present river throughout its whole course. The foregoing conditions have given rise to the statement expressed in the Main Report that "geologically the St. Lawrence is a new river" (para. 25).

61. Indications of the changes which the river has undergone are frequent. While it appears generally to have preserved its uniformly straight course from Lake Ontario to Montreal, there are frequent instances of local variations as disclosed by rock borings, which may have some bearing upon future construction on the river. Modern theories of river hydraulics may explain these variations by changes in discharge, by some rock and earth erosion, by ice gorging, etc., but this river, with its great volume of water, appears to have kept very closely to its relatively straight course.

62. Thousand Island Section. The rock surfaces through this section, as found by hydrographic surveys are very irregular. The shoals to be excavated are granite, characteristic of this region.

63. International Rapids Section. General: The material overlying the rock throughout this section is generally a mixture of clay, sand, gravel, and boulders, with clay predominating. These are compacted into occasional masses of hardpan. Boulders occur frequently; they commonly form a pavement on the bed of the river especially where the current is swift; they are also frequently found in layers in the bodies of the islands and on the mainland, and almost invariably form the upper strata and caps of the high spots or knolls. As excavation work proceeds it is possible certain deposits of both sand and gravel may be found suitable for construction but these are likely to be limited.

64. The rock in the International Rapids Section as indicated by borings, is generally limestone of various degrees of hardness and varying thickness of strata with occasional seams of shale and sandstone. A good portion of the rock, where excavated, may be used for different classes of construction, but only a limited quantity is suitable for concrete or other uses where uniformly hard and durable rock is required.

Geological records (Geological Survey of Canada, Ottawa and Cornwall Sheet, No. 120, 1906), show calciferous dolomite between Chimney Point and Ogden Island and at Farrans Point and in the Long Sault Rapids. They show Chazy limestone with occurrences of Chazy shale with bands of sandstone between Ogden Island and the foot of the section. No geological faults have been found in the district. All rock encountered in this section appears to be quite strong and impervious.

65. Galop Rapids. The head of Galop Rapids is formed by a rock ridge with its uneven surface filled in by boulder pavement. This ridge, which constitutes the control for the level of Lake Ontario and virtually forms the bed of the river, may be said to vary across the two channels, between Elev. 224 and 228.

66. The following boring record is given in order to present an idea of the typical character of the rock and its overburden in this general locality.

ON GALOP ISLAND

Location	On North side of Galop island, near shore in large bay, about 3,000 feet below upper shore of island (on centre of proposed channel).	
Done	June 16, 1926, by United States Section with "Well" Drill (Boring No. S. 14, Index No. P. 144).	
Elevation	255.7	Ground surface
	255.7 to 247.6	Clay
	239.0	Normal water level
	247.6 to 220.7	Hardpan with boulders
	220.7	Rock surface
		Medium blue limestone
	210.7	Bottom of drilled hole

67. Ogden Island. At Ogden Island a rock sill crosses the north channel at Elev. 202 and a similar rock sill crosses the south channel at Elev. 214. At the lower end of the island the general level of rock appears to range around Elev. 175 while further down below Canada and Clark Island, it is more irregular varying under the river bed, between Elev. 150 and 170. Extensive boring data is available in this locality.

68. The following boring records are herewith given as typical in this locality, the two selected being on the North shore of Ogden Island and alongside the main channel of the river.

OGDEN ISLAND

Location	On Point North side of Ogden Island, upper side of deep bay and about 4,500 feet from lower end of island.	
Done	September, 1923, by Can. Dept. of R. & C. with "Well" drill (Boring No. 9, Index No. 116).	
Elevation	240.8	Ground surface
	240.8 to 230.3	Clay
	230.3 to 221.8	Sand and Gravel with Boulders
	218.0	Normal Water Level
	221.8 to 202.5	Sand and gravel
	202.5 to 198.6	Gravel with stones
	198.6 to 196.6	"Hard" and "Soft" rock (limestone)
	196.6	Rock Surface
		Limestone
	190.3	Bottom of drilled hole

OGDEN ISLAND

Location	Near shore, north side of Ogden Island, about 800 feet above lower end of island.	
Done	July, 1923, by Can. Dept. of R. & C. with "Well" drill (Boring No. 3, Index No. 108).	
Elevation	226.4	Ground Surface
	215.0	Normal water level
	226.4 to 197.9	Sand and gravel with boulders
	197.9 to 195.9	Boulder, limestone
	195.9 to 191.4	Sand and gravel
	191.4 to 174.4	Sand and gravel with clay
	174.4 to 173.7	Sand
	173.7	Rock Surface
	173.7 to 171.5	Medium and soft limestone
	171.5 to 164.2	Medium hard limestone
	164.2	Bottom of drilled hole.

69. Crysler Island. At and in the vicinity of Crysler Island about forty borings have been made, this being an alternative location for a dam and power house. The borings showed marked irregularity in the underlying rock surface and water under pressure was found in several holes. The core borings made after the completion of the Main Report, however, disclose more favourable foundation conditions further down stream.

70. Typical rock borings, above and below Crysler Island are as follows:—

CRYSLER ISLAND

Location	At shore upper end of Crysler Island, midway between main banks of river.	
Done	October, 1921. by Can. Dept. of R. & C. with "Well" drill (Boring No. 1, Index No. 106).	
Elevation	213.0	Ground surface
	208.0	Normal water level
	213.0 to 181.0	Hardpan with boulders
	181.0 to 176.0	Hardpan with small stones
	176.0 to 165.5	Clay hardpan (Boulder at 168.0)
	165.5 to 159.0	Sand gravel and a little clay
	159.0 to 155.7	Quicksand
	155.7 to 142.0	Hardpan
	142.0 to 140.2	Sand and fine gravel
	140.2	Rock surface
	140.2 to 139.2	Slate rock
	139.2 to 135.9	Limestone rock
	135.9	Bottom of drilled hole.

CRYSLER ISLAND

Location	In river, 100 feet below lower point of Crysler Island, midway between main banks of river.	
Done	October, 1924, by Canadian Section with core drill (Boring No. 11, Index No. 104).	
Elevation	207.4	Water surface
	192.5	River bed
	192.5 to 183.1	Loose sand and gravel
	183.1 to 174.8	Sand and loose gravel
	174.8 to 167.5	Fine sand and coarse gravel
	167.5 to 158.7	Sand
	158.7	Rock surface
		Limestone
	141.6	Bottom of cored hole.

71. Long Sault Rapids. The river bed forming the head of Long Sault rapids consists of a limestone sill or ridge with its crest at about Elev. 180, which it is to be observed is higher than the rock at Chrysler island, twelve miles upstream. At the proposed dam site, opposite the head of Barnhart island, the rock drops off to elevations ranging between 150 and 160. The exploration of this site, by methods hereinbefore described in detail, shows that the rock has ample bearing power for a dam structure.

72. The overburden in the banks and in the islands in the locality of this upper Barnhart Island Dam site, is of the usual boulder clay formation. The midstream shoal at this point is hard blue clay, with a paving of cobbles and boulders.

73. The proposed dam and power house site at the foot of Barnhart island was explored for foundation conditions, both in the river itself, on the mainland and on Barnhart island. Within the river, six cored borings were sunk to depths of from 10 to 30 feet into the rock. The rock, at the general elevation of from 107 to 111, was limestone and drilling records indicate it to be impervious. The overburden in the river, about 30 feet in thickness, is clay, sand,

gravel, and boulders, generally hard and dry but with some water bearing seams. On the United States mainland, on the powerhouse site, the rock ranges from Elev. 104 to 109 and on the Canadian power house site on Barnhart island, from about Elev. 110 to 125.

74. Considering the United States mainland, both above and below Hawkins point, much attention was paid to investigation of the overburden because upon its impermeability will depend the security of this portion of the development if water is raised by a main dam across the river at the foot of Barnhart island. Various borings were put down along the river shore which indicate that the rock is lower around Hawkins point than further down at the power house and dam site.

75. A study was also made of the character of this area comprising a stretch of about three miles in length and especially of that lying under the oval contour 200 extending above and below Hawkins point. Particular attention was paid to the water bearing strata as disclosed by the numerous wells on the farms in the locality. The top portions of knolls here, around Elev. 220 and 225, have the same predominating caps and shallow layers of boulders as elsewhere along the river, the boulders being embedded in a clay or hard-pan crust which holds rain and surface water in small ponds or swamps. There are sand and gravel strata below these, alternating with layers of hardpan and boulders. The water bearing strata hereabouts lie between Elev. 165, just about the surface of the water in the river, and Elev. 185, which is about the elevation of the top of the main clay or hardpan beds. Most of the water strata down river from Hawkins point are found about Elev. 165 and those above Hawkins point at Elev. 175 to 185. It is considered that for construction purposes, this long contour can be made reasonably impervious for the head that may be imposed, care being taken to secure tight connections to the main hardpan stratum at about Elev. 185.

76. On Barnhart island a similar situation would be created and in like manner special attention was paid to investigating both rock and overburden. The most critical portion of Barnhart island in this respect is the lower third, as it is here that the island will be called upon, under any method of power development, to act as an earth dam having a dyke on its crest to hold water above its present ground surface. Such necessity raises the question of the impervious character of the material overlying the rock.

77. Barnhart island is characteristic of all the St. Lawrence islands in this Section. Clay is mixed with sand, gravel, and boulders but in quite irregularly formed strata and at different levels.

78. Selecting 13 typical borings in the lower third of the island with special reference to the materials overlying the rock, the following several features emerge: In only one locality does water occur at an elevation above the river; this appears to come from ponds and surface sources. There is nothing in the borings or surface indications to cause a suspicion that river water finds its way in significant quantity from the higher to the lower reaches by means of underground channels either in or beneath the island. The higher levels carry boulders with coarse gravel and sand and some clay which occurs in pockets. Intermediate levels carry sand and gravel with some strata of clay; these are sometimes compacted into hardpan. The lower levels, next to rock, invariably are of sand and fine gravel interspersed with layers of coarse materials and sometimes found tightly compacted. The same conditions prevail on Sheek island where similar investigations were carried out.

79. Considering the lower portion of Barnhart island where it will be called upon to sustain water at a high level, the borings indicate that the materials overlying the rock will be satisfactory for the foundation of the earth dykes, provided they are properly prepared.

80. Borings along the navigation canal route between Robinson Bay and Grass river were made to supplement those made in 1900 by the Deep Waterways Board. Those at the Robinson Bay lock site showed continuous hardpan to rock which is at Elev. 122. Seven borings cored into rock were made at the Grass River Lock site; the overburden is soft blue marine clay, in general extending to rock which is at about Elev. 104.

81. In order to convey some idea of the characteristics of these several critical localities at and about Long Sault rapids, five typical borings in addition to the two shafts already described, have been selected and their records are as follows:—

BARNHART ISLAND AND LONG SAULT RAPIDS

I

Location.. .. ..South side Barnhart Island near shore about 3,000 feet below Point opposite Robinson Bay.

Done .. ..May 8, 1923, by Canadian Dept. of R. & C. with "Well" drill (Boring No. 17, Index No. 48).

Elevation..	196.5	Ground surface
	196.5 to 194.5	Clay
	194.5 to 187.5	Sand and gravel with boulders
	187.5 to 178.5	Sand and gravel
	162.0	Normal water level
	178.5 to 119.5	Sand and gravel with clay
	119.5	Rock surface
		Limestone
	116.5	Bottom of drilled hole.

II

Location.. .. ..Centre of lower portion of Barnhart Island 2,500 feet up from the lower end and in the forebay of "Two Stage" Power House site.

Done .. ..March 20, 1922, by Canadian Dept. of R. & C. with "Well" drill (Boring No. 4, Index No. 41).

Elevation..	210.0	Ground surface
	210.0 to 182.5	Sand and gravel with boulders
	182.5 to 170.0	Gravel with clay
	170.0 to 159.0	Sand and gravel
	159.0 to 154.0	White sand and coarse gravel
	154.0 to 152.0	"Layer of limestone" (Boulder?)
	152.0 to 151.6	Sand and gravel
	151.6 to 146.3	Clay hardpan
	146.3 to 145.9	Sand and gravel
	145.9	Rock surface
		"Hard" limestone
	133.9	Bottom of drilled hole

III

Location.. .. ..Midstream, Main Channel, southeast of and opposite lower end of Barnhart Island, on "Single Stage" Dam and Power House site.

Done .. ..May, 1926, by United States Section, with core drill (Boring No. R. 1, Index No. P. 53).

Elevation..	159.0	Water surface
	141.1	River bed
	141.1 to 131.1	Sand and gravel
	131.1 to 122.5	Sand and gravel, with clay
	122.5 to 112.8	Sand and gravel, with clay and water
	112.8 to 110.7	Sand and gravel, with water
	110.7	Rock surface
		Limestone
	89.5	Bottom of cored hole.

IV

Location...........	On United States mainland, near shore in bay 3,500 feet below Hawkins Point on "Single Stage" Power House site.	
Done...........	April 6, 1925, by United States Section, with core drill. (Boring No. P. 5, Index No. P. 59).	
Elevation..........	186.0	Ground surface
	159.0	Water level
	186.0 to 105.8	Sand and clay, with boulders. Material required blasting at some places down to Elev. 137.0 to drive casing.
	105.8	Rock surface
	105.8 to 100.8	Blue limestone "shattered to some extent"
	100.8 to 80.8	Blue limestone, "hard and solid"
	80.8	Bottom of cored hole.

V

Location...........	On Canal Line, near Robinson Bay Lock Site about 3,000 feet below Robinson Bay.	
Done...........	May 14, 1926, by United States Section with core drill. (Boring No. P. 6, Index No. P. 64).	
Elevation..........	190.8	Ground surface
	190.8 to 182.8	Soft clay
	163.0	Normal water level in Robinson Bay
	182.8 to 122.4	Hardpan with boulders
	122.4	Rock surface
		Blue limestone
	104.0	Water lost
	97.4	Bottom of cored hole.

82. Lake St. Francis Section. In lake St. Francis some deposits of sand were found near its head, but, in general, the material to be removed in the channels consists of soft mud overlying sand and gravel. The land area south-east of the lake consists of layers of peat overlying clay.

83. Soulanges Section. The material overlying the rock surface throughout this section is boulder clay in the ridges and marine clay in the flat portions. The marine clay appears to have been deposited after the boulder clay; in some cases both materials were found in the same boring.

84. The overburden at the upper end of this section is not very deep and in many cases the rock is close to the ground surface. This is especially so in the Coteau rapids, while at the upper end of Grande île there is much rock outcrop, and most of the wells on this island are quite shallow. The overburden on Grande île is boulder and marine clay and no sand or gravel was encountered in any of the borings except at the east end of the island.

85. Between Cascades point and Cascades island, and on the latter, the solid rock surface is exposed but it falls off rapidly toward the Ottawa arm of lake St. Louis.

86. In Coteau rapids, crystalline limestone is exposed and is of a specially hard gritty nature. In Cedars rapids, dolomite is exposed and in Cascades rapids, Potsdam sandstone.

87. On the south side of the river, along the line of the Hungry bay-Melocheville canal location as proposed in the report of 1921, the overburden is marine clay overlying gravel and sand, except along the St. Louis river, where rock outcrops and boulder clay ridges rise through the surface of the marine clay. The high ground between the St. Louis and St. Lawrence is heavily capped with boulder beds. At Melocheville, solid sandstone rises to the surface and has been quarried in some places.

88. Along the north shore of the river from Coteau to Cascades, the overburden is all marine clay although some sand and gravel is found in borings made near Coteau Landing. On île Juillet and île aux Vaches, clay, sand, and gravel overlie the rock. Some sand and gravel were also found in the borings put down in the river above île Juillet.

89. Boulders and boulder pavements on the river bed and the islands are frequent throughout the whole section. When the river bed was exposed during the construction of the Cedar Rapids Power works, the bed of the head canal was found to be covered with boulders.

90. In general the rock surface in and on the shores of the river above Coteau rapids is about elevation 126. Similarly, it is at about elevation 100 at the upper end of Cedars rapids and from elevation 80 to 85 at the top of Cascades rapids.

91. Four typical borings in this section have been selected as indicating the character of rock and overburden. Their records are as follows:—

COTEAU DU LAC

I

Location	Near shore, north side of river above Coteau du Lac, opposite Prisoner's island (at mile 145 and on Coteau du Lac lock site).	
Done	May 13, 1925, by Canadian Section with "Well" drill. (Boring No. 11, Index No. 29)	
Elevation	150.2	Ground surface
	150.2 to 146.7	Clay
	143.0	Normal water level
	146.7 to 138.7	Sand and gravel
	138.7 to 131.2	Sand and gravel with clay
	131.2 to 129.4	Sand and clay
	129.4	Rock surface
		Limestone ("Fairly hard")
	111.9	Bottom of drilled hole.

ILE JUILLET

II

Location	In river, 1000 feet upstream from Ile Juillet. (On line of proposed dam).	
Done	October 30, 1925, by Canadian Section with core drill (Boring No. 4, Index No. 50).	
Elevation	126.4	Water surface
	118.4	River bed
	118.4 to 105.0	Sand and coarse gravel
	105.0 to 101.0	Sand and gravel with clay
	101.0	Rock surface
		Limestone
	84.3	Bottom of cored hole

HEAD OF CEDARS RAPIDS

III

Location	In river, midstream, 300 feet north of lower end of Ile Juillet, toward Ile aux Vaches. (On power house site).	
Done	November 10, 1925, by Canadian Section with core drill. (Boring No. 6, Index No. 55)	
Elevation	125.1	Water surface (swift)
	115.1	River bed
	115.1 to 103.9	Sand and coarse gravel with clay
	103.9 to 100.8	Sand and coarse gravel
	100.8	Rock surface
		Limestone
	90.1	Bottom of cored hole.

CHAMBERRY GULLY

IV

Location	In Chamberry Gully, on canal location below Chamberry Gully lock (at mile 155)	
Done	April 27, 1921, by Canadian Dept. R. & C. with "Well" drill. (Boring No. "S", Index No. 19)	
Elevation	98.0	Ground surface
	98.0 to 78.5	Clay
	78.5 to 62.8	Gravel
	62.8	Rock surface
		Hard sandstone
	54.8	Bottom of drilled hole.

92. Lachine Section. The material overlying the rock in this section is mostly of clay with small amounts of sand and gravel, usually near the rock and in comparatively thin layers. From above Lachine to the mouth of the Montreal Aqueduct and from the foot of Lachine rapids to Montreal, the river is strewn and paved with boulders. In the borings, however, especially along the shores, very few boulders were encountered.

93. The surface of the rock is exposed in many places throughout this section both on the shores and on the islands, and in the form of shoals and ridges in the river and rapids. On the north shore between Lachine and Verdun, the rock surface is above the bed of the river but it drops off east of Verdun and from there to Montreal is generally below the bed of the river.

94. The rock found in the borings in the eastern end of lake St. Louis was shale or soft limestone. There is a large outcrop of Chazy limestone along the shore at Caughnawaga, while east of this point it is Trenton limestone, also exposed. Further east this is replaced by Utica shale. In the Lachine rapids there are frequent igneous dykes or intrusions through the shale, running across the river northwesterly; these outcrop on Heron island and on both main shores. The shale disintegrates very rapidly on exposure but the igneous rock weathers well.

95. The general surface of the rock opposite Lachine is at about Elev. 50 and this approximate level holds until near the head of Lachine Rapids. The general level at the foot of Lachine rapids is between Elev. 18 and 24 which holds along the north shore to Verdun. The rock along the proposed canal route then rises following the shore until near Victoria bridge where it is about Elev. 30. Thence it rapidly falls to about Elev. minus 6 in the upper end of Montreal harbour.

96. Three typical borings have been selected for this section, the records of which are as follows:—

LACHINE RAPIDS

Location	On south shore at head of Lachine rapids, opposite upper end of Ile au Diable (near dam site).	
Done	February 2, 1925, by Canadian Section with "Well" drill. (Index No. 67).	
Elevation	59.2	Earth surface
	57.0	Normal water level
	59.2 to 54.2	Earth and stones
	54.2	Rock surface
	54.2 to 52.2	Slate rock
	52.2 to 47.3	Shale and slate
	47.3 to 46.1	Slate rock
	46.1 to 40.2	Shale and slate
	40.2 to 38.2	Hard slate
	38.2 to 33.2	Shale
	33.2 to 16.2	Slate
	16.2 to –3.8	Black shale and clay
	–3.8 to –5.3	Slate
	–5.3 to –20.0	Black shale and clay
	–20.0 to –25.5	Limestone
	–25.5	Bottom of drilled hole.

LACHINE RAPIDS

Location.. .. ..Island, north side of river about 2,000 feet west of present Lachine power house and 1,300 feet from river (near guard gate site)

Done.. .. ..August 10, 1925, by Canadian Section with "Well" drill. (Index No. 60).

Elevation..	66.9	Ground surface
	66.9 to 63.9	Hard sand
	63.9 to 59.9	Sand and clay
	59.0	Normal water level (head canal)
	59.9 to 56.9	Clay
	56.9 to 54.2	Gravel and stone
	54.2 to 50.0	Slate gravel
	50.0	Rock surface
	50.0 to 39.5	Slate rock
	39.5	Seam of sand and water ($\frac{1}{2}$-inch)
	39.5 to 34.9	Rock, very hard
	34.9 to 31.7	Rock (softer)
	31.7	Bottom of drilled hole.

AT VERDUN

Location.. .. ..At shore, north side of Nun's Island opposite Verdun pump house (on canal location, mile 180)

Done.. .. ..February 19, 1924, by Canadian Section, with "Well" drill. (Index No. 10).

Elevation..	40.7	Water surface (winter)
	33.3	Normal water level (summer)
	32.9	River bed
	32.9 to 23.5	Sand and gravel
	23.5	Rock surface, shale
	23.5 to 18.3	Shale
	18.3	Rock surface, slate
	18.3 to –6.8	Slate
	–6.8	Seam of sand
	–6.8 to –11.4	Slate
	–11.4	Bottom of drilled hole.

97. Information concerning the geology of the St. Lawrence river, between Prescott and Lachine, is contained in a "Report on Structural Materials" in this section, published by the Canadian Department of Mines, 1922. References to other geological reports are given on pages 12 and 13 of that publication.

Adopted by Board, June 2, 1927.

APPENDIX B

LAKE LEVELS AND OUTFLOWS

1. This appendix sets forth the data and computations on which the conclusions relating to the Great Lakes in Part II of the Report are based.

DESCRIPTION

2. Areas and Storage Capacity. The areas of the Great Lakes are as follows:—

	Square Miles
Lake Superior (including St. Marys river above St. Marys falls)	31,820
Lake Michigan	22,400
Lake Huron—(including St. Marys river below St. Marys falls)	23,010
Lake St. Clair (including St. Clair river)	460
Lake Erie (including Detroit river)	9,940
Lake Ontario (including Niagara river and St. Lawrence river to Galop rapids)	7,540
Total	95,160

3. The Great Lakes form an enormous reservoir system which equalizes the flow of the St. Lawrence river. In this system lakes Michigan and Huron are a single unit, since they are joined by the broad and wide straits of Mackinac and have always substantially the same level. Lake St. Clair can be included, without material error, in the reservoir capacity of lake Erie.

4. The flow of water that would be furnished by drawing down the several lakes by one foot, or conversely the flow required to increase the depth on the lakes by one foot, is as follows:—

	Cfs. for One Month
Lake Superior	337,100
Lakes Michigan-Huron	481,200
Lake Erie	110,200
Lake Ontario	80,000
Total	1,008,500

5. A draw down of one foot on the lake system as a whole would provide the entire average flow delivered to the St. Lawrence for more than four months. It is of interest to note that the entire flow of the Mississippi river past New Orleans at flood time would raise the Great Lakes at the rate of but little more than one foot per month.

6. Supply. The water supply of the Great Lakes is furnished by the inflow of the many relatively small rivers of their drainage basins, increased by the rainfall on the lakes themselves, and decreased by the evaporation from the lake surfaces. The total area of the drainage basin of the lakes is approximately 300,000 square miles, of which nearly one-third is occupied by the lakes themselves. Computations show that the average supply received from the land areas about equals that received as rainfall on the lakes, but that roughly 40 per cent of this total gross supply is lost by evaporation. (Table 45, pp. 367-368, Report on Diversion of Water from the Great Lakes, 1919.)

7. The net supply to any lake, from month to month, can be determined from the inflow from the lake above, the outflow from the lake, and the change

in level during the month. The annual supply to the entire lake basin, from 1860 to 1925, as determined by such computations (par. 72 to 89), has varied from a maximum of 342,000 cfs. per annum in 1873 to a minimum of 145,700 cfs. per annum in 1895, with an average for the entire period of 242,000 cfs.

8. The seasonal variation in supply swings between much wider limits. It is highest in the spring months of April to June, and lowest in the fall months, October to December. The average net supply of the lake basin by months from 1861 to 1925 has been as follows:—

Spring and Summer	Cfs.	*Fall and Winter*	Cfs.
March	367,800	August	178,600
April	533,900	September	89,200
May	538,900	October	41,300
June	445,300	November	19,700
July	304,900	December	61,400
		January	110,400
		February	208,500
Average	438,200	Average	101,300

9. During the high year of 1873 the supply for the month of April was at the rate of 825,500 cfs. During the low year of 1895, the lake system as a whole lost during the two months of October and November more water from evaporation than it received from all sources, the deficiency being 51,500 cfs. per month and 35,500 cfs. per month respectively.

10. The monthly supplies to the individual lakes, from 1860 to 1925, are given in tables 1 to 7, appendix B.

11. Outflow of the Lake Basin. The average yearly outflow from the Great Lakes basin, including the outflow through the canal of the Chicago Sanitary District, has ranged from 285,400 cfs. in 1861 to 205,500 cfs. in 1895. The monthly outflow has ranged from an average of 318,000 cfs. in May, 1870, to an average of 174,200 in February, 1872. This minimum was due to ice retardation. The minimum discharge with open-river conditions was in November, 1895, and amounted to an average of 194,000 cfs. for the month. The average total outflow from 1861 to 1925 has been 246,100 cfs. The apparent discrepancy between the mean supply given in par. 7 and the mean outflow is reconciled by the relative lake levels at the beginning and end of the period.

12. The recorded maximum and minimum monthly outflows occurred prior to the opening of the Chicago Drainage canal, and the figures given represent, therefore, the limits of variation of discharge into the St. Lawrence.

13. The total outflows through the Chicago Sanitary District canal are given in the following tabulation, extracted from the Report on the Illinois River published in House Document 4, 69th Congress, 1st Session:—

Year	Yearly Mean Discharge, Cfs.	Year	Yearly Mean Discharge, Cfs.
1900	2,990	1913	7,839
1901	4,046	1914	7,815
1902	4,302	1915	7,738
1903	4,971	1916	8,200
1904	4,793	1917	8,726
1905	4,480	1918	8,826
1906	4,473	1919	8,595
1907	5,116	1920	8,346
1908	6,443	1921	8,355
1909	6,495	1922	8,858
1910	6,833	1923	8,348
1911	6,896	1924	9,465
1912	6,938	1925	8,277

14. Annual Fluctuation in Lake Levels. The annual fluctuation of the lake levels in absorbing the seasonal irregularities of supply has been as follows:—

	Average Feet	Maximum Feet
Superior	1¼	2.67
Michigan-Huron	1¼	2.58
Erie	1½	2.99
Ontario	2	4.17

15. Extreme Ranges of Monthly Mean Lake Levels. Extreme high and low waters are reached at the end of periods of excessive or deficient supply extending over several years. The mean highest and lowest average monthly levels of the Great Lakes between 1860 and 1925, in feet above mean sea level, are shown in the following tabulation:—

—	Mean elevation	Maximum	Minimum	Range
Superior at Marquette	602·24	604·08 (Sept., 1869)	600·54 (April, 1911)	3·54
Michigan at Milwaukee	581·02	583·57 (June, 1886)	577·47 (Dec., 1925)	6·10
Huron at Harbor Beach	581·02	583·66 (July, 1876)	577·61 (Dec., 1925)	6·05
Erie at Cleveland	572·46	574·52 (June, 1876)	570·39 (Dec., 1925)	4·13
Ontario at Oswego	246·11	248·95 (May, 1870)	243·41 (Nov., 1895)	5·45

16. Temporary Oscillations of Lake Surfaces. Superimposed on the rise and fall of the level surfaces of the lakes shown by the monthly mean levels, there are occasional oscillations due to wind and barometric pressure, by which the water is raised temporarily by several feet in a part of the lake, and depressed by an equivalent amount in another. Lake Erie particularly is subject to such disturbances. Its fluctuations reach their maximum at Buffalo, due to the configuration of the shore line at the east end of the lake. During a westerly gale the water has risen 8 feet above its monthly mean level at Buffalo; and the water at Buffalo has been known to fall 4 feet below its monthly mean level. While these extremes are uncommon, fluctuations of one or two feet, lasting for a few hours, are not uncommon, and more or less rythmic fluctuations of several inches, known as seiches, are nearly always occurring on all the lakes except Ontario.

17. Levels Prior to 1860. The systematic recording of the levels of the lakes was not begun until 1860. The gauge records prior to that date are generally not continuous, and the datum to which some are referred is not certain. The lakes reached an unusually high level in 1838, and this high water level was for years used as a reference plane for lake levels. The high water level of 1838 on lake Erie is established at 575.11, which is 0.6 feet above the highest monthly mean level since 1860; on lake Michigan, the high water of 1838 is 584.69, which is 1.1 feet above the maximum monthly mean level since 1860. The high water of 1838 on lakes Superior and Ontario was established by inference rather than by records, but has been carried as 605.32 for lake Superior, and 248.98 for lake Ontario. For Superior, this high water datum plane is 1.2 feet above the highest monthly mean level recorded since 1860; on Ontario, the monthly mean level for May, 1870, was practically at the 1838 high-water plane.

The old records further indicate that in 1819 the lakes may have been at substantially the low levels of 1925.

18. Earth Tilt. The records of the several water-level gauges on the Great Lakes show a gradual steady rise of the earth surface on the northerly shores of the lakes relative to that on the southerly shores. This movement of the earth's surface is in the same direction as that which occurred in past ages, as shown by the levels of old beaches. The axis of the present tilting as a whole is

approximately 20 degrees north of west, and the rate of tilting is in the vicinity of one-half foot per hundred miles per hundred years, with indications of a somewhat greater rate in the northern areas.

The effect of this local tilting on the water levels and depths of water at any locality on any lake varies with the distance of this locality from an axis drawn through the controlling sill of the outlet to the lake.

The maximum effect of this movement of the earth's surface on Great Lakes levels should be felt in the lower St. Marys river, which is some 200 miles from an axis drawn through the outlet of lake Huron. If the tilting of the earth continues at the present rate it is to be expected that the depths in the channels and in the lower entrances to the locks in that river may be reduced by one foot in a hundred years. It is to be expected that the channels and lock structures will be deepened to meet the growing demands of commerce long before any substantial effect is felt from this slow movement of the earth's surface.

Detailed discussions of the subject are contained in an article entitled "Tilt of the Earth in the Great Lakes Region" by Mr. Sherman Moore, Assistant Engineer, United States Lake Survey, published in the Military Engineer, May-June, 1922, pages 153 *et seq.*; and in a paper "Recent Earth Movements in the Great Lakes Region" by Dr. G. K. Gilbert, printed in Part II of the Report of the United States Geological Survey, 1896, pages 595 to 647.

DIVERSIONS AND OUTLET ENLARGEMENTS AFFECTING LAKE LEVELS

19. Diversions and Regulating Works, St. Marys River. The outlet of lake Superior is the St. Marys River, the natural control section of which is the rock sill at the head of the 17 to 20-foot incline at St. Marys falls. Diversions of water into power canals, which draw water from above the falls and discharge it below the falls, was begun in 1895 and subsequently increased until at the present time nearly the entire flow of the river at low stages is drawn through the canals.

20. The existing diversions are as follows:—

A—*In the United States*—

(1) By the Michigan Northern Power Company under leases granted under authority of section 12, River and Harbour Act of March 3, 1909.

By lease dated May 28, 1914, and expiring June 30, 1944, 25,000 cfs. primary water and 5,000 cfs. secondary water.

By lease dated September 10, 1918, and expiring June 30, 1944, 3,000 cfs. additional secondary water.

(2) By the Edison Sault Electric Company as a part of lease of power works, dated June 25, 1912, and expiring June 30, 1942, issued under authority of section 11 of River and Harbour Act of March 3, 1909; sufficient water to operate said works with additions, not exceeding an aggregate total capacity of 5,335 horsepower at 14-foot head over and above the power required by the United States for its own use.

(3) By the navigational canals and locks operated by the United States.

B—*In Canada*—

(1) By the Great Lakes Power Company, under grant from the Department of Lands and Forests, Province of Ontario, by virtue of Orders in Council of June 20, 1914, September 4, 1914, and March 11, 1919, covering the right to use 20,000 cfs.

(2) By the Canadian Government for the operation of the navigation canal and lock.

21. The mean flows during 1925 were as follows:—

Power diversion, Michigan Northern Power Co.	29,983
Power diversion, Edison Sault Electric Co.	1,411
Navigation canals, United States	796
Power diversion, Great Lakes Power Co.	19,344
Navigation canal, Canada	106
River	4,846
Total	56,486

22. Obviously these power canals have greatly enlarged the natural discharge capacity of the river. The natural capacity had previously been somewhat reduced by the construction of the piers and embankments of a railroad bridge at the head of the rapids. As the diversion for power increased, its effect on the levels of lake Superior was first compensated for by contracting the river. There was a limit however to which such contractions could be carried. The flow through the natural outlet had ranged from about 50,000 cfs. at low stages to 130,000 cfs. at high stages, and this variation in discharge must be preserved to hold lake Superior within its natural range of stages. If the channel were contracted, say to one-half, in order to permit the diversion of 25,000 cfs. without diminishing the low stages of the lake, the discharge capacity at high stages would be not far from one-half of 130,000 cfs. plus the diversion of 25,000 cfs.; a total of but 90,000 cfs. The high levels of the lake would therefore be increased.

23. To overcome this situation, the power companies were required to install gates by which the low-water discharge over the falls could be curtailed without curtailing the total high-water discharge. The gates now extend completely across the river. With the control gates and the power canals, the discharge from lake Superior can be varied at will from no discharge up to approximately 100,000 cfs. at low lake stages, and from no discharge up to 130,000 cfs. at high lake stages. The contractions made in the river reduce its capacity at high stages to approximately the same extent that the power canals have increased this capacity, so that the gross discharge capacity is now substantially the same at high stages as originally.

24. The control gates are operated under a Board of Control in accordance with conditions laid down by the International Joint Commission. Application having been made by the Michigan Northern Power Company and the Algoma Steel Corporation, respectively, for approval of the obstruction, diversion, and use of the waters of the St. Marys river, the Commission, in parallel Orders and Opinions dated May 26 and May 27, 1914, after reciting that the equal division of the water between the United States and Canada was conceded upon the hearing by their duly appointed representatives, granted the applications, subject to conditions, some of the more important provisions of which are as follows:—

All compensating works heretofore built and all such works built under this order of approval and all power canals, including their head-gates and by-passes, shall be so operated as to maintain the level of lake Superior as nearly as may be between levels 602.1 and 603.6 above said mean tide at New York, and in such manner as not to interfere with navigation. The operation of all the said works, canals, head-gates and by-passes for the above purposes shall be under the direct control of the board hereinafter authorized, which board shall be known as "The Board of Control."

The officer of the Corps of Engineers charged with the improvement of the falls of the St. Mary's river on the American side and an officer appointed by the Canadian Government shall form said board whose duty it shall be to formulate rules under which the compensating works and power canals and their head-gates and by-passes shall be operated so as to secure as nearly as may be the regulations of lake Superior as set forth herein. It shall be the further duty of said board to see any rules or regulations now or hereafter made by proper authority for the control of said works are duly obeyed.

To guard against unduly high stages of water in lake Superior the rules formulated by said board, when tested by the physical conditions which existed during any year of recorded high water in lake Superior, when the monthly mean elevation of the lake exceeded 603.6 above said mean tide at New York shall give no monthly mean level of the lake greater than the maximum monthly mean actually experienced in said year.

To guard against unduly high stages of water in the lower St. Mary's river, the excess discharge at any time over and above that which would have occurred at a like stage of Lake Superior prior to 1887, shall be restricted so that the elevation of the water surface immediately below the locks shall not be greater than 584.5 above said mean tide.

At all times said board shall determine the amount of water available for power purposes. Said board will cause the amount of water so used to be reduced whenever in its

opinion such reductions are necessary in order to prevent unduly low stages of water in lake Superior, and will fix the amounts of such reductions; Provided, that whenever the monthly mean level of the lake is less than 602.1 above said mean tide of New York, the total discharge permitted shall be no greater than that which it would have been at the prevailing stage and under the discharge conditions which obtained prior to 1887; provided further, before any flow of primary water on either side of the river is reduced the use of all secondary water shall be discontinued.

"Primary water" as used herein shall be understood to mean the amount of water which is continuously available for use for power purposes. "Secondary water" shall be understood to mean an amount of water, over and above that designated as primary water, is intermittently available for use for power purposes.

25. The operation of the regulating works has affected the levels of lake Superior, and also the levels of the lower lakes, since the controlled discharge out of the lake is at times greater than the natural discharge and at times less. To evaluate effect of this variation, it is necessary to know what the natural discharge would have been. Since the outflow of the St. Marys river had been modified by various works prior to its first discharge measurements, in 1896, its original discharge can be inferred only. For this reason the regulated discharges were compared with the discharge that would have taken place under conditions existing in 1902, prior to the completion and operation of the control gates, when the discharge relation was well established. On this basis of comparison, it is found that during the first period of operation of the regulation works, until 1917, an excess of water was discharged, with the consequence that the levels of lake Superior were lowered, and those of the lower lakes raised. From 1917 to 1922 water was generally held back in lake Superior, with the consequence that its levels were raised, and those of the lower lakes made lower than would otherwise have occurred. From 1923 to date the release has been again above normal, with the consequence that, by January of 1926, lakes Michigan-Huron were 3 inches, lake Erie $1\frac{1}{2}$ inches, and lake Ontario 1 inch above what they would have been without the regulation of lake Superior.

26. The results are set forth in the following tabulation, and graphically on plate 1, appendix B.

TABLE 8—EFFECT OF PRESENT REGULATION OF LAKE SUPERIOR, 1914-1925

Changes due to regulation	Lake Superior		Lake Mich.-Huron		Lake Erie		Lake Ontario	
	Amount	Date	Amount	Date	Amount	Date	Amount	Date
Maximum Stage *with* regulation..	603·81	Sept., 1916	581 92	June, 1918	573·85	July, 1917	247·95	June, 1919
Maximum Stage *without* Regulation............	604·18	Oct., 1916	581·80	July, 1918	573·79	June, 1919	247·84	July, 1919
Minimum Stage *with* Regulation.	600·74	Mar., 1925	577·61	Dec., 1925	570·39	Dec., 1925	244·22	Jan., 1925
Minimum Stage *without* Regulation............	600·51	April, 1924	577·41	Dec., 1925	570·29	Dec., 1925	244·26	Nov., 1925
Maximum Increase in Stage (ft.)....	0·85	Dec., 1922	0·37	July, 1917	0·25	Sept., 1917	0·24	Jan., 1918
Maximum Decrease in Stage (ft.).......	0·81	July / Aug. 1917	0·38	Nov., 1922	0·26	Dec., 1922	0·25	April, 1923
Maximum Increase in Discharge (Sec. ft.)........	25,000	Aug., 1920	6,390	June 1917	5,420	Sept., 1917	4,970	Jan., 1918
Maximum Decrease in Discharge (Sec. ft.)	18,000	Dec., 1918 Aug., 1919 July, 1921	6,530	Oct., / Nov. 1922	5,630	Dec. 1922 Jan., 1923	5,220	April., 1923

OUTLET ENLARGEMENTS AND DIVERSIONS LAKES MICHIGAN-HURON

27. Description. The outlet of lakes Michigan-Huron is through the St. Clair river, lake St. Clair, and the Detroit river, into lake Erie. The total fall from lake Huron to lake Erie averages about 8.5 feet, of which 5.5 feet takes place in the St. Clair river and 3.0 feet in the Detroit river.

28. The St. Clair river is approximately 40 miles in length. At the entrance from lake Huron, the river is contracted in a deep and narrow channel known as the Port Huron rapids through which the mean velocity reaches to from 5 to 6 feet per second. The fall through this section is somewhat less than 1 foot in a distance of two miles. The river then flows for 25 miles with a mean depth of about 30 feet, a mean velocity of about $2\frac{1}{4}$ feet per second, and with a slope of 0.15 feet to the mile. It then divides and enters lake St. Clair through several delta channels, the one improved for navigation being 13 miles in length. The fall through the delta section of the river is about one foot. The bed and banks of the St. Clair river are generally sand and gravel. It has no controlling rock sill.

29. The Detroit river is about 31 miles in length. Through the upper 13 miles the river is a deep slow flowing stream. The lower part of the river is wide, split by islands, and is crossed by a wide sill of ledge rock.

30. Both the St. Clair and the Detroit rivers are subject to ice gorging in winter, which reduces the flow by varying amounts, not unfrequently to one half of the summer flow for the same stage and fall.

31. Discharge Formula, St. Clair-Detroit Rivers. The discharge from lake Huron, during the ice free months, with the present regimen of the rivers, is given by the following formula, derived from recent studies made by the United States Lake Survey of all discharge measurements.

(1) $Q = 87.98\ [(HB - 554.25) + 0.8\ (Cl - 554.25)]^{1.8}\ (HB - Cl)^{0.5}$

Where Q=discharge in cubic feet per second,
HB=elevation Lake Huron (Harbor Beach gage).
Cl=elevation lake Erie (Cleveland gage).

32. Effect of a Diversion from Lake Michigan. A diversion from lake Michigan or Huron will eventually lower the levels of these lakes sufficiently to reduce the discharge capacity of the St. Clair-Detroit rivers by the amount of the diversion. The effect of such a diversion, if the diversion is small in comparison with the total flow of the rivers, can be derived directly from the discharge equation and is—

(2) $\triangle H = D\ (Q/2F + Q/R)\ + \triangle h\ (R - 1.6F)/(R + 2F)$

$\triangle H$=effect of diversion on lake Huron,
D is the amount of the diversion.
F=fall, HB—Cl.
$R = .556(HB - 554.25) + .444(Cl - 554.25)$
$\triangle h$=effect of diversion on lake Erie as determined by regimen of Niagara river. (Par. 59).

33. From equation (2) it is apparent that the effect of a given diversion from lake Michigan on the levels of lakes Michigan and Huron depends on the elevation of these lakes and of lake Erie. Three representative levels are as follows:—

	Lakes Michigan-Huron	Lake Erie
Low levels	578.0	570.25
Mean levels	581.0	572.5
High levels	582.6	573.8

34. The computed effect of the authorized diversion of 8,500 cfs. from lake Michigan by the Chicago Sanitary District (par. 59-62 of Report) is then as follows:—

At low levels..	0.56 foot
At mean levels..	0.49 foot
At high levels..	0.45 foot

It will be noted that the influence of the lake elevations on the effect of the diversion is not great. The precise effects computed would be realized only if the lakes remained constantly at the respective elevations and in an ice free condition for several years. The levels taken as low lake levels have not extended over a sufficiently long period of time to exercise their full influence on the effect of the diversion. The greatest refinement regarded as justifiable is that the effect of a diversion of 8,500 cfs. from lake Michigan is to lower lakes Michigan and Huron by 0.5 foot, or 6 inches.

35. The actual effect of the present diversion of the Chicago Sanitary District on the levels of lakes Michigan-Huron is subject to the uncertainty as to extent to which this effect is modified by the winter ice gorging of the river. When the outflow is diminished by ice gorging, a given lowering of the levels of lake Huron probably diminishes the discharge capacity of the river by a less amount than under ice free conditions. The lowering of the levels of lake Michigan and Huron required to reduce the average annual discharge capacity of the river by the amount of a given diversion should therefore be somewhat greater than the amount computed for continuous ice free conditions. A reasonable procedure is to take the value of Q in formula (2) par. 32, as the average annual flow, as determined by the best evidence as to winter retardation. On this basis, the computed effect of the total reported diversion, during each of the past five years, if continued indefinately at the mean lake levels of those years, would be as follows:—

Year	Amount of diversion	Estimate average discharge from Lake Huron	Average elevation		Computed effect of diversion (feet)
			Huron	Erie	
1921	8,355	175,900	580·03	572·30	0·54
1922	8,858	175,500	579·89	572·00	0·57
1923	8,348	169,600	579·28	571·41	0·54
1924	9,465	163,900	579·02	571·68	0·62
1925	8,277	153,800	578·14	570·87	0·56
Average					0·566

The estimated present effect of the actual diversion is therefor 0.56 feet.

36. These results are greater than those found in earlier studies, first because they are based on lower lake levels, and second because recent low-water discharge measurements have afforded better data on the relation between the discharge of the St. Clair-Detroit rivers, their stages, and fall.

37. Black River Diversion. There is a minor diversion of water from lake Huron through a small canal into the Black river, which discharges into the St. Clair river at Port Huron. The diversion is for flushing sewage out of the river. It was authorized by the United States by a permit issued by the Secretary of War, May 14, 1901. A current-meter measurement made in 1926 showed a discharge of 150 cfs., and the capacity of the canal is insufficient to carry a materially greater amount. The effect of this diversion on the levels of lakes Huron and Michigan is inappreciable.

38. Effect of Diversions From Lake Erie on Levels of Michigan-Huron. The back-water effect of the diversions from lake Erie on the levels of lakes Huron and Michigan is given by the formula:—

$$\triangle H = \triangle h (R - 1.6F)/(R + 2F)$$

where $\triangle H$ is the effect on lake Huron-Michigan,
$\triangle h$ is the effect on lake Erie.
R and F are as indicated in par. 32.

Within the ranges of levels normally occurring, the effect on lakes Huron-Michigan varies generally between 22 per cent and 27 per cent of the effect on lake Erie. At the average levels obtaining during the last 5 years, the percentage is 25.6. The effect of the authorized diversions through the Welland Canal (par. 52) on the levels of lakes Michigan-Huron is therefore 0.025 foot, or approximately ¼ inch. The effect of all present diversions from lake Erie (par. 53) is approximately 0.05 foot, which may be increased to 0.07 foot after the new Welland ship canal is opened.

39. Changes in Discharge Capacity of St. Clair River. The bed of the St. Clair river is not inherently stable, and an unchanging regimen of the river cannot be taken for granted. Systematic discharge measurements of the river were not begun until 1899. Changes prior to 1899 can only be inferred.

40. As explained hereafter (par. 77 to 79) the derivations of the discharges from lake Huron made for the purpose of determining the supply factors during these early years, disclosed an apparent increase between 1890 and 1900 in the discharge capacity of the St. Clair river relative to the Detroit river. Since the discharge capacity of the Detroit river cannot well have decreased during this period, it must be assumed that the discharge capacity of the St. Clair increased. This increase in discharge capacity is represented by the two equations:—

(3) Prior to 1890; $Q = 100\ [(H - 552{\cdot}84) + 0{\cdot}6(h - 552{\cdot}84)]^{1{\cdot}8}(H-h)^{0{\cdot}5}$

(4) 1895 to 1900; $Q = 100\ [(H - 552{\cdot}12) + 0{\cdot}6(h - 552{\cdot}12)]^{1{\cdot}8}(H-h)^{0{\cdot}5}$

Where H is the elevation of Lake Huron (Harbour Beach gage); h is the elevation of Lake St. Clair (St. Clair Flats gage).

It is found that, at representative elevations in the vicinity of 575·75 on Lake St. Clair and 581·0 on Lake Huron, the second of these equations will give the same values of Q as the first, if the value of H is decreased by from 0·3 to 0·4 feet. The two equations represent therefore an increase in discharge capacity equivalent to between 0·3 and 0·4 feet of stage on Lake Huron during the period.

41. The deduction just made is open to the doubt as to stability of the St. Clair gage during the period, since precise level lines on the delta of the St. Clair run subsequently to 1900 show progressive subsidence of bench marks in the locality. A reasonable assumption as to the rate of settlement prior to 1900 is in itself sufficient to explain the apparent increase in the discharge capacity of the St. Clair River above inferred. On the other hand, if an increase in the discharge capacity of the Detroit River occurred during the period, the increase in the discharge capacity of the St. Clair would be greater than was deduced in the preceding paragraph.

42. The changes in the discharge capacity subsequent to 1900 are discussed at some length in the body of the report where they are found to be equivalent to a decrease of 0·3 feet in the stages of Lake Huron. The changes

in terms of changes in stage on Lake Huron are derived from the changes in the constants of the discharge formula given in paragraph 77, in the same manner as indicated in paragraph 40.

The computations of the Canadian Section, based on data largely supplied by the United States Lake Survey, indicate 0·61 feet of lowering of stage of Lake Huron due to channel enlargement between the years 1899 and 1925. The computations of the Canadian Section show that 0·29 feet of this change in stage can be explained by channel enlargement in the Port Huron rapids, opposite Point Edward.

DIVERSIONS, LAKE ERIE

43. Description.—The outlet of lake Erie is the Niagara river. A broad sill of ledge rock extends across the entrance to the river from the lake. Below the rapids, formed by this sill, there is a reach of quietly flowing river, which terminates in the rapids just above Niagara Falls. Diversions upstream from the latter rapids have some effect on the levels of Lake Erie.

44. The diversion of the Chicago Sanitary District reduces the supply of Lake Erie by exactly the amount of this diversion, and lowers the lake levels correspondingly. Other diversions affecting the levels of Lake Erie are made through:

The Welland Canal,
The Black Rock Canal.

45. The following diversions for power purposes have been authorized on the Welland Canal by the Department of Railways and Canals of the Dominion of Canada:—

Hamilton Cataract Power, Light and Traction Co., leases totalling..	1,010 cfs
Corporation of St. Catharines..	50 "
Provincial Paper Mills, Ltd..	760 "
Total..	1,820 "

All of these diversions discharge into lake Ontario. In addition, diversions aggregating 260 cfs. have been authorized from the Welland Canal to the Welland river, which enters the Niagara river at the foot of the Grass Island pool. About 10 per cent of the effect of this diversion on Lake Erie levels is thereby restored.

46. The actual total flow from lake Erie into the present Welland Canal, for both power and navigation purposes, as determined by random discharge measurements made by the Department of Railways and Canals in 1922, 1923, and 1924, is approximately 3,400 cfs. during the navigation season and 2,500 cfs. during the remainder of the year, an average throughout the year of 3,100 cfs.

47. The new Welland Ship canal for deep-draught vessels is so designed that a flow of 6,000 cfs. can be drawn from lake Erie without interfering with its use by shipping. The Chief Engineer, Department of Railways and Canals, authorizes the statement that the diversion through the new Welland Ship Canal, including both the water required for lockage and that for power purposes, will not exceed 5,000 cfs.

48. The Black Rock canal is a navigation canal alongside the upper part of the Niagara river. It is operated by the United States Government to carry navigation past the rapids at the head of the river to the industries on the river below them, and to the entrance of the present New York State Barge canal at Tonawanda. The diversion from Lake Erie through this canal is approximately 1,000 cfs., much of which finds its way into the Niagara river through the river wall of the canal. The remainder is discharged into the Niagara river at the lock at the foot of the canal.

49. The New York State Barge canal diverts a flow estimated at 1,500 cfs. from the Niagara river at Tonawanda, the water being eventually discharged into lake Ontario. Of this total a flow of 275 cubic feet per second is classified as for power purposes. The effect of this diversion on the levels of lake Erie is negligible.

50. Power companies in the United States and Canada divert considerable quantities of water from the river upstream from the rapids at the heads of the Falls; under the treaty of 1909. These diversions have been compensated for, at least to a considerable degree, by intake structures and the deposit of dredged material. The remaining effect on the levels of Lake Erie is negligible. (See page 381, Report on Diversion of Water from the Great Lakes and Niagara River, 1921.)

51. Effect of Diversions. The discharge formula for the Niagara River is:

$$Q=3904(H-558{\cdot}37)^{1{\cdot}5}$$

Where H is the elevation of Lake Erie on the Buffalo gage.

From this formula it is easily shown that the rate of increase in the discharge capacity of the Niagara river per foot rise of Lake Erie, commonly called the increment for the Niagara river, is as follows:—

At lake elevation 570.25 (low level)	20,190 cfs
At lake elevation 572.5 (mean level)	22,000 "
At lake elevation 573.8 (high level)	23,000 "

52. The authorized diversions have the following effect on the levels of Lake Erie:—

—	Amount of diversion	Effect in feet at		
		Low level (elev. 570·25)	Mean level (elev. 572·5)	High level (elev. 573·8)
Chicago Sanitary District	8,500	0·42	0·39	0·37
Power leases on Welland Canal	2,050	0·10	0·09	0·09
Total		0·52	0·48	0·46

53. The actual present diversions have the following effects on Lake Erie:—

Chicago Sanitary District (8,660 cfs)	.41
Welland Canal (3,100)	.15
Black Rock Canal	.04
Total	.60

The increased diversion required for the operation of the new Welland Ship canal is expected to bring the total to 0.68 foot.

EFFECT OF DIVERSIONS LAKE ONTARIO

54. Description.—The outlet to lake Ontario is the St. Lawrence river, the control section of which is the limestone ledge forming the sill of the Galop rapids. The Galop canal, for 14-foot navigation, lies along the river bank at these rapids.

55. The levels of lake Ontario have been affected by the diversion of the Chicago Sanitary District, by diversions for power and navigation through the Galop canal, and by a contraction of the Galop rapids known as the Gut Dam. The diversions authorized by license from the Galop canal amount to 988 cfs.

56. Effect of Diversions.—The formula developed by the United States Lake Survey for the flow into the St. Lawrence river is as follows:—

$$Q=3428(H-229.13)^{1.5}$$

Where H is the elevation of lake Ontario (Oswego gage). The increment for the St. Lawrence has the following values:—

	Cfs.
At lake elevation 244.5 (low level)	20,160
At lake elevation 246.0 (mean level)	21,120
At lake elevation 247.5 (high level)	22,040

The computed back-water effect of the small diversion at the Galop is 75 per cent of the effect if made directly from lake Ontario.

57. The effect of authorized diversions on the levels of lake Ontario is therefore as follows:—

—	Amount of diversion	Effect in feet at		
		Low level (elev. 244·5)	Mean level (elev. 246·0)	High level (elev. 247·5)
Chicago Sanitary District	8,500	0·42	0·40	0·39
Galop Canal	988	0·04	0·03	0·03
Total		0·46	0·43	0·42

58. As explained in the body of the report the Gut Dam in the Galop rapids has raised the levels of lake Ontario by somewhat more than 0.4 feet.

SUMMARY

59. The results are summarized as follows:—

Cause	Amount of diversion, cubic feet per second	Effect, in feet, on levels of Lakes		
		Michigan and Huron	Erie	Ontario
Authorized diversions—				
Chicago Sanitary District	8,500	−0·5	−0·4	−0·4
Power diversions, Welland Canal	2,050	−0·025	−0·1	0
All present diversions and outlet changes—				
Chicago Sanitary District	8,660	−0·5	−0·4	−0·4
Welland Canal	3,100	−0·04	−0·15	0
Black Rock Canal	1,000	−0·01	−0·05	0
Changes in St. Clair River outlet—				
Gravel dredging		−0·3		
Other changes		−0·3		
Gut Dam				+0·5
Total		−1·15	*−0·6	+0·1

*Upon the opening of the new Welland Ship Canal the lowering of the level of Lake Erie will be increased to 0·7 foot.

IMPROVEMENT OF LAKE LEVELS AND OUTFLOWS

60. Compensating Works.—As explained in the body of the report, the levels of the lakes can be raised by fixed contractions in their outlet rivers. Such works will raise the high levels substantially as much as the low levels. If the high levels of the lake are not to be increased, the works must therefore be only sufficient to correct the effect of existing diversions and outlet enlargements. They are therefore termed compensating works. After the lake levels have adjusted themselves to the new regimen of the outlet, the outflow from the lake will be substantially the same after as before compensating works have been built.

61. Regulating Works.—Regulating works are essentially dams with sluice gates constructed in the outlets to the lakes, so as to control the outflows and hence the lake levels.

62. Scope of Investigations.—Regulating works are already in operation in the St. Mary's river at the outlet to lake Superior. The regulation of lake Ontario is an inherent part of the plans for the improvement of the St. Lawrence proposed in the report. The present investigation is therefore limited to determining—

(*a*) The benefits and cost of a comprehensive system of lake regulation with works at the outlets of lake Michigan-Huron and of lake Erie.
(*b*) The benefits and cost of compensating works at these outlets.
(*c*) A suitable program for the regulation of lake Ontario alone.

63. Prior Proposals.—In 1900, the Board on Deep Waterways, in presenting plans and estimates for securing deep draft navigation from the Great Lakes to New York harbour (House Doc. 149, 56th Congress, 2d Session) included regulating works at the head of the Niagara river which were designed to hold lake Erie to a substantially uniform level at elevation 574.7. This proposal was reviewed by the International Waterways Commission, a joint board of Canadian and American engineers, who submitted a report in 1910 (Sessional Paper No. 19a, 3 George V, p. 775 *et seq;* and H. Doc. 779, 61st Cong. 2d Sess.), after an elaborate study extending over several years. This report pointed out that, on account of the irregularity of supply to the lake, it was impossible to hold lake Erie to a fixed level; but that it would be held by regulating works between the limits of 572.0 and 574.5; thereby raising the low water levels by 1.4 feet without increasing the high water levels. Such regulation would, however, have increased the fluctuations in lake Ontario and reduced the extreme recorded water level of that lake by 4 inches, with consequent reduction in the extreme low open-river discharge of the St. Lawrence. The Board recommended that the regulation of lake Erie be not undertaken, but in a supplementary report recommended the construction of compensating works in the Niagara river about a mile and a half above the rapids at the head of the falls, so designed as to raise the low levels of lake Erie by 0.45 foot, and the high levels by 0.38 foot.

64. In a comprehensive report on the Diversion of Water from the Great Lakes and the Niagara River, made by Col. J. G. Warren in 1919 in accordance with a resolution of the Congress of the United States, it was recommended that compensating works consisting of submerged rock sills be placed in the Niagara and St. Clair rivers to correct the results of existing diversion. In the review of this report by the Board of Engineers for Rivers and Harbours, preference was expressed for regulation works in lieu of compensating works at the outlet of lake Erie.

65. Finally, an Engineering Board of Review engaged by the Sanitary District of Chicago has presented a scheme for the regulation of the Lakes as a whole. The works proposed include a dam with gates at the foot of the Grass Island Pool in the Niagara River, for the regulation of the outflow from Lake Erie; and a dam with gates and locks in the St. Clair River, for the regulation of the outflow from Lakes Michigan-Huron. By the operation of these works, together with the operation of existing works at the outlet of Lake Superior, and of works in the St. Lawrence built in connection with the improvement of that river for navigation and power, it was proposed to hold the levels of the lakes normally between the limits shown in the subjoined tabulation. The actual maximum and minimum levels occurring since 1860 are placed in a parallel column for comparison.

Lakes	Normal regulated range proposed by Engineers for Sanitary District	Actual range of stage since 1860
Superior	602—604.5	600.5—604.1
Michigan-Huron	581—583.5	577.5—583.7
Erie	573—574.5	570.4—574.5
Ontario	246—248.5	243.4—248.95

66. The report recognizes that the lakes could not be held within the limits stated during periods of extreme rainfall. At such times they would rise above the limits fixed; but it was computed that no period of high rainfall that has occurred subsequent to 1860 would raise the levels above the high-water datum of 1838. It apparently was not recognized that with the lakes normally held at such high levels, the rainfall which produced the high water of 1838 would raise the lakes above the level it then had. The report indicates, however, that the regulated levels to be finally chosen should be based on further investigation of the damages that might be caused thereby. The discharge of the Niagara river was to be kept normally between 180,000 and 200,000 cfs. with discharges of 250,000 cfs. at times of high rainfall. The monthly mean discharge of the Niagara river proper has varied between the limits of 162,000 cfs. and 253,000 cfs.

67. Comparison of Benefits from Regulation and Compensation. It will be noted that prior proposals for the construction of compensating works have been limited to correcting the effects of existing diversions, so that the high levels of the lake would not be raised above the levels that would occur without these diversions. Obviously, riparian interests on the Great Lakes would be injured to exactly the same extent by high levels created by regulating works, as by the same high levels created by compensating works. The benefits to be derived from regulating works in comparison with compensating works must be evaluated therefore by considering the reduction in the fluctuation of lake levels, together with the improvement of outflows, that can be secured through the operation of these works, since the reduction in fluctuation measures the amount by which the low levels of the lake can be raised without increasing the high levels.

68. Possibilities of Regulation Indicated by Mass Curve. On Plate 2, Appendix B, is shown a mass curve of the supply to the Great Lakes, from 1860 to 1925, under the supposition that a diversion of 8,500 cfs. were made from the lake basin during the entire period. From this diagram it can be seen that *provided there were no limitation on the maximum discharge on the St. Lawrence or of the interlake rivers* the following results could be obtained by a complete system of regulation:—

With a fluctuation of 5·75 feet on all the lakes a uniform discharge of 233,000 cfs. could be maintained.

With a fluctuation of 4·0 feet on all the lakes a minimum discharge of 230,000 cfs. could be maintained.

With a fluctuation of 3·0 feet on all the lakes, a minimum discharge of 220,000 cfs. could be maintained.

With a fluctuation of 2·3 feet a minimum discharge of 210,000 cubic feet per second could be maintained.

With a fluctuation of 2·0 feet a minimum discharge of 200,000 cubic feet per second could be maintained.

69. The actual fluctuations of the several lakes during the period is given in paragraph 15. But it has been shown that lakes Michigan and Huron were lowered by diversions and outlet enlargements of 1·15 feet during the period between the recorded high and recorded low waters; and Lake Erie by 0·6 feet during this period. Correcting the fluctuations by these amounts, and weighting the fluctuations of the individual lakes by their areas, it is found that the weighted average fluctuation of all the lakes, exclusive of the increased fluctuations to progressive diversions and enlargements, is 4·3 feet. The apparent possibilities of regulation, *except as limited by the discharge capacities of the several outlets* is therefore as follows:

The low water levels could be raised by 2·3 feet and a minimum discharge of 200,000 cfs. maintained.

The low water levels could be raised by 2·0 feet and a minimum discharge of 210,000 cfs. maintained.

The low water levels could be raised by 1·3 feet and a minimum discharge of 220,000 cfs. maintained.

A minimum discharge of 230,000 cfs. could be maintained without raising the present high levels or lowering the present low levels.

70. The results given in the preceding paragraph are impossible of attainment on account of the limitations of outlet discharge. Thus, to maintain a discharge of 220,000 cfs with a fluctuation of 3 feet in the lake levels it would be necessary throughout the years 1920 and 1921 to limit the discharge to that figure. In the early months of these years the lakes would have been within 1.2 feet of their maximum levels. But if the lakes had been allowed to rise to within 1.2 feet of their maximum levels during the early months of 1912 or of 1913, then a subsequent average yearly discharge of 300,000 cfs down the St. Lawrence would not have kept the levels within the maximum. Having regard to winter limitations of discharge capacity, an average yearly discharge of 300,000 down the St. Lawrence is regarded as excessive rather than practicable. It would have been impossible to foretell in the spring of 1920 that a period of 6 years of deficient supply would occur, or prior to 1912 that a period of two years of excess supply would occur, and without this foreknowledge the apparent results derivable from regulation could not be achieved with the limited discharge capacity of the St. Lawrence. Physical limitations on the discharge capacity of the Niagara, St. Clair-Detroit and St. Marys rivers similarly curtail the results indicated by a study of a general mass curve.

71. Detailed Studies of Lake Regulation. To determine the true possibilities of lake regulation, it is necessary to work out in detail the results that

would be secured by the best programs of regulating the discharges of the lakes, had such programs been in effect in the past. The data required for that purpose include—

(a) The supplies to each lake from 1860 to 1925.

(b) The permissible high water levels of each lake.

(c) The maximum and minimum outflows of each outlet river physically practicable or permissible.

SUPPLIES TO THE LAKES

72. General Aspects. The total net supply to a lake for any month is the outflow corrected for the gain or loss of storage in the lake. The local supply is the total supply less the inflow from the lake above.

73. On account of the oscillation of the lake surfaces, the gage records on any day do not give the true lake level for that day. For purposes of determining the monthly gain or loss of storage in a lake, the elevation of the lake at the first of each month is taken as the mean of the monthly mean levels of the given and preceding months.

74. The reliability of the determinations of total and local net supply depends upon the reliability of the computations of the monthly discharge. Systematic discharge measurements of the outflow from the various lakes were not begun before the late 90's. The earlier discharges must be based on an estimate of prior changes in the gage-discharge relation due to changes in the discharge capacity of the river.

75. Lake Superior. The discharges of the St. Mary's river and the monthly supplies to lake Superior from 1860 to 1907 were computed by the International Waterways Commission from measurements made between 1896 and 1902, and by a detailed analysis of the prior changes in the outlet capacity of the river (par. 25 to 58, and tables 19 and 24, of Appendix to Report of Jan. 8, 1910). These were reviewed and extended to 1909 by Messrs. Noble and Woodward, Consulting Engineers, in an unpublished report dated June 29, 1912, to the Michigan Lake Superior Power Company, which was used as a basis for the present regulation of lake Superior. Slight modifications were made in the prior determinations on account of later data regarding the capacity of the side channels at the control section of the river. The determinations of Messrs Noble and Woodward are used in the present report and are extended to 1925, inclusive, from the records of discharge through the power canals, navigation canals, and in the river, which are maintained by the United States Engineer Office at Detroit in connection with the operation of the navigation works at St. Mary's Falls, and the supervision, on the part of the United States, over the control works. The supply to lake Superior is given in table 1 of this appendix, and the discharge of the St. Mary's river in table 9.

76. Lakes Michigan-Huron. The discharge out of lake Huron through the St. Clair river, lake St. Clair, and the Detroit river depends upon the elevations of both lake Huron and lake Erie. The discharge measurements, which commenced in 1899, show that changes in the discharge capacity, have occurred subsequent to 1899, and gage records prior to that date indicate some instability in the regimen of the outlet. (See par. 39 to 42.)

77. The United States Lake Survey has made an extended study of the present and past discharges from lake Huron. This study is not yet completed, but has progressed sufficiently to warrant the modification of prior determinations.

The discharge formula for the St. Clair river while ice free, as developed from this study, is:—

(1) $Q=100\ [(H-B)+0.6(h-B)]^{1.8}(H-h)^{0.5}$

Where Q=discharge in cubic feet per second,
H=elevation of Lake Huron (Harbour Beach gage).
h=elevation Lake St. Clair (St. Clair Flats gage).
B=is a constant.

The values of B as derived from the discharge measurements are as follows:—

To July, 1900	552.12
August, 1900, to December, 1908	552.38
January, 1909, to December, 1909	552.32
January, 1910, to December, 1911	551.96
January, 1923, to December, 1925	551.58

No meter measurements were taken between 1911 and 1923.

78. The corresponding relation between the flow and the elevations of Lake St. Clair (St. Clair Flats gage) and Lake Erie (Cleveland gage) is

(2) $Q=597.6\ [0.5(h-555.60)+0.5(C-555.60)]^{1.8}(h-c)^{0.5}$,

where h is elevation on St. Clair Flats gage and
C is elevation on Cleveland gage.

This relation is not applicable to the period between 1907 and 1912, when the regimen of the Detroit river was modified by the cofferdams of the Livingstone channel.

79. The formula for the flow prior to 1899 (ice-free months) is based on the assumption that there was no change in the regimen of the Detroit river. The values of the constant B in equation (1) corresponding to the flows derived from equation (2) are as follows:—

1860 to 1890	552.84
1891 to 1894	552.48
1895 to 1899	552.12

Equation (1) was used to determine the flow during the ice-free months except during the period 1912 to 1922, in which equation (2) was used.

80. For the period prior to the establishment of the Harbour Beach gage, in 1875, the Milwaukee gage was substituted therefor. The early elevations of the St. Clair Flats gage are the computed elevations published in the Annual Report of the Chief of Engineers for 1904.

81. To determine the discharge during the winter months, similar formulas were derived for each pair of consecutive gages for which records are available, the discharge for the winter months computed from every such pair, and the minimum discharge so determined was taken as the winter discharge on the assumption that in at least one of the reaches approximate open-water regimen would exist. For the period subsequent to 1900, such records are available through reaches with minimum ice retardation, and the determinations are regarded as fair. Prior to 1899, the records of only three gages are available, lake Huron, lake St. Clair, and lake Erie, so that when, as was often if not generally the case, the flow of both the St. Clair and the Detroit rivers was retarded by ice, the computed flows for the winter months are much in excess of those that actually occurred.

82. The warning must therefore be given that the winter discharge under natural conditions prior to 1899, shown in table 10, are too large, that the supplies to lakes Michigan-Huron during the winter months in tables 2 and 3 prior to 1899 are too large; and that the supplies to lake Erie during the winter months in tables 4 and 5 are too small by the same amounts. A comparison

of the average local supplies to lake Erie for January, February and March for the period from 1860 to 1900, with the average for the same months during the period from 1901 to 1925, shown in table 5, indicates clearly the extent of the errors introduced by the lack of data on which to base the effect of ice retardation during the earlier period.

83. The errors introduced by the lack of data on winter retardation in the St. Clair-Detroit rivers affect only the distribution of the supply between lake Erie and lakes Michigan-Huron. The total supply to the three lakes is not affected. In the computations hereinafter described of the effect of programs for regulation, it is assumed that the winter discharge through the regulating works would be retarded in the same percentage as is the unregulated discharge during the month. The error introduced in the computations of regulated outflow and lake levels is therefore reduced to the difference between the true and the apparent retardation applied to the difference between the regulated and natural flow, and is not regarded as of sufficient consequence to alter the conclusions.

84. For purposes of computing storage, the elevation of lakes Michigan and Huron was taken as the mean of the Milwaukee and Harbour Beach gages since the establishment of the latter in 1875, and the Milwaukee gage previously.

85. Lake Erie. Successive meterings have shown no change in the discharge capacity of the Niagara river, and the outflow from lake Erie was derived from the formula:—

$$Q=3904\ (H-558.37)^{1.5}$$

in which H is the elevation of lake Erie, as shown by the Cleveland gage records from 1860 to 1886, inclusive, and by the Buffalo gage records from 1887 to 1925.

To the discharge so computed the following was added as the estimated flow through the diversions via the Welland canal and the head of the Niagara river:—

From 1860 to 1880	1,000 cfs
1881 to 1905	2,000 "
1906 to 1910	3,400 "
1911 to 1915	4,500 "
1916 to 1925	5,500 "

86. Lake Ontario. The outflow and supplies, tables 6, 7, and 12, to lake Ontario were based on a study made by Mr. D. W. McLachlan, Department of Railways and Canals, Chairman of the Canadian Section of the Board.

87. The storage in lake Ontario has been derived from records of the Oswego gage. The discharge values were obtained from gage readings at the various locks along the St. Lawrence canals, especially Locks No. 21, 23, 24, and 25. A deduction of 6 per cent has been made for ice retardation in all values derived for January, February, and March except those obtained from records of gage readings at Lock No. 27. For the latter an extra deduction of 6,000 cfs was made for these months.

88. The discharge ratings for the various lock gages were revised in March, 1926, and are based on measurements of the United States Lake Survey made in 1908, 1911, 1913 and 1914, and of the Canadian Department of Railways and Canals in 1923, 1924, and 1925 .

89. Correction for Chicago Diversion. The supplies are those which would have occurred had a diversion of 8,500 cfs. from lake Michigan taken place throughout the period. To this end the total supplies to lakes Michigan-Huron, Erie, and Ontario were diminished by 8,500 cfs less the actual diversions given in par. 13.

PERMISSIBLE HIGH LEVELS OF LAKES

90. An extended investigation to determine how high the various lakes might be raised without unwarranted damage to the industries, cities, and lands along their shores was made, at the request of the Board, by the District Engineers in charge of harbour works on the lakes in Canada and the United States. A tabulation of the probable damages reported is given in tables 13 to 15. A summary of the conclusions reached is given in the following paragraphs. In this summary it is convenient to use the term " flood level " to indicate the level at which material damage begins.

91. Lake Superior. On lake Superior the flood level was fixed at elevation 603.6 by the International Joint Commission in 1914, after hearing representatives of cities, towns, and industries on that lake; and the rules for the regulation of the lake provide that its level shall be permitted to rise above that limit only under such conditions of extraordinary rainfall as would cause such a rise without regulation.

92. In September, 1916, lake Superior had a mean stage of 603.88. At this time, basements of a number of warehouses and manufacturing establishments along the water front in Duluth were flooded and trouble was experienced in the sewer system of Superior, Wis. In reporting on this situation the United States District Engineer at Duluth states:—

> I am quite confident that had the monthly mean level of Lake Superior reached its maximum of 603.6 during the time that it has been under complete regulation there would have been a strong movement from many of the interests about Lake Superior to have that maximum lowered, for there is no doubt that many properties would be seriously affected not so much by that actual mean height, but the heights to which it would rise temporarily under certain wind and barometric conditions.

93. From plate 3 it will be seen that lake Superior will reach 603.6 about once in twenty years. This curve is based upon the records of the years 1901 to 1925 inclusive, but the result for this lake is the same if the entire period is used.

94. Lakes Michigan-Huron. Some damage would result on lakes Michigan-Huron at as low an elevation as 580.5. If the lakes rose above 581.0 there would be damage to docks, basements, and sewage systems in Green Bay, Wis., Alpena, Michigan, and Sarnia, Ont. The power output of the hydro-electric plant at Sault Ste. Marie would be reduced. Damage might result in Chicago and vicinity, as many of the sewers are now overloaded and flood basements during heavy rains, which flooding would be increased by any raising of the lake levels above their outlets. The ground-water levels in the city would also be raised, making construction more difficult. At lake levels above 581.6, damage would result to jetties of the Chicago district, and from sliding of high banks. Damage would result to docks in Sarnia and Port Huron, and the operation of docks and elevators of the Canadian National Railway at Port Edward and Goderich would be interfered with. Lake levels above elevation 582 would interfere with operations of plants at Port Huron and of most of the structures between the French and St. Mary's rivers, also with wharves at Alpena, Muskegon, and Green bay. Lake levels above elevation 583 would flood basements in downtown Milwaukee and Manitowoc, and would cause unwarranted damage at Alpena, Holland, and Muskegon, Mich., and Racine, Wis. Levels above elevation 583.5 would flood docks at Alpena and Mackinac Island and would interfere with operations of the municipal lighting plant at the latter place. Levels above 583.7 would flood docks in Port Huron.

95. In view of the foregoing information, the flood level of these lakes should not be placed above 582.2, and under the regulated condition the lakes should not exceed this level in height, frequency, or duration to a greater extent than in the past. From plate 3 it will be seen that on the basis of the records of the last 25 years, a stage of 582.2 would probably be reached once in twenty years and has the same probability as the elevation selected for lake Superior.

96. Lake Erie. Some damage would result on lake Erie at elevations below 573, principally through erosion on the lake shores. Above 573, the dock of the Detroit and Cleveland Navigation Co. in Detroit and the operation of the power plant of the Cleveland Electric Illuminating Co. would be inconvenienced. Lake levels above 573.5 would damage some docks in Detroit, Rondeau, and Port Stanley. Levels at 574.0 or slightly above would interfere with the operations of the Maple Leaf Milling Co. at Port Colborne, Ont., the Pittsburgh and Conneaut Dock Co. at Conneaut, Ohio, the Solvay Process Co. and the Michigan Central Railroad at Detroit, the unloading plants of the Erie Railroad at Cleveland, and the elevators of the Washburn-Crosby Co. at Buffalo. They would also damage the works of the Ohio Public Service Co. at Lorain, Ohio, interfere with the drainage works of the Bethlehem Steel Co. at Lackawanna, and flood the turn-table pit of the Canadian National Railways at Dover, and some of the docks of the Detroit Sulphite and Paper Co. at Detroit. Lake levels above 574.5 would interfere with operations of the Candler Dredge and Dock Co. at Detroit. Lake levels above 575 would interfere with unloading operations of the Pennsylvania Railroad at Buffalo, Erie, Sandusky, Ashtabula, and Cleveland, of the Buffalo Creek Railroad at Buffalo, interfere with the operations of the National Tube Co. at Lorain, Ohio, and the Commercial Milling Co. at Detroit, flood some docks of the Standard Oil Co. and Candler Dredge and Dock Co. at Detroit, and damage the property of the Hammermill Paper Company at Erie.

97. From a consideration of the above information, elevation 573.9 was selected as the flood level, which should not be exceeded more frequently than in the past. This elevation has the same frequency probability, as shown by the records of the past 25 years, as the levels selected for the other lakes.

98. Lake Ontario. On lake Ontario, damage below elevation 247 is uncertain but probably small. Above elevation 247, drainage of cellars in the lower part of Kingston would be affected and the dock and canning factory of the Port Millford Packing Co. at Port Millford would be flooded. Lake levels above elevation 247.5 would flood wharves, coal sheds, warehouses, etc. in Kingston, Brockville, Prescott, Port Milford, Bath, South Bay, Ogdensburg, and Charlotte. They would affect the LaSalle Causeway at Kingston and the Kingston dry dock. At lake levels above 248, damage would result as follows: Docks, storehouses, and factories in addition to those before mentioned would be flooded or interfered with in Kingston, Wellington, Port Millford, Clayton, Cape Vincent, Sacketts Harbour, Oswego, Fairhaven, Little Sodus Bay, Sodus Point, and Charlotte and on the lower Niagara river. Such levels would render less efficient or damage the breakwaters and other aids to navigation at Sacketts harbour, Little Sodus bay, Great Sodus bay, Oswego, Charlotte, and Olcott. In addition to this, damage would probably be done to a number of other docks, roads, bridges, an electric railway, and several beaches. Above 248.5, damage would be done to additional docks, coal sheds, and factories in Kingston, Rednersville, Wellington, Massagana, Northport, and Forester Lt. Lake levels above elevation 249 would seriously damage a number of other important interests in Gananoque, Kingston, Green Island, Prescott, and Ogdensburg.

99. After considering the foregoing information, elevation 248.1 was selected as the flood level for lake Ontario, which should not be exceeded by the regulated levels to a greater extent than was the case in the past. The data on flooding damage is more nearly complete on lake Ontario than on the other lakes and indicates that a great deal more damage would result than is shown by the data for the other lakes. Plate 3 shows that, for this elevation also, the probable frequency, indicated by the last 25 years of records, was once in 20 years.

100. SUMMARY. The flood levels on the several lakes may be taken, therefore, as follows:—

Lake Superior	603.6
Lakes Michigan-Huron	582.2
Lake Erie	573.9
Lake Ontario	248.1

101. It will be observed that the damages, as a rule, are not due to the dead level of the lake itself, but to the temporary fluctuations above that level caused by winds and barometric pressure, to the flooding of sewers by heavy rains which may happen to occur when the high lake levels have reduced their outlet capacity, and to the raising of flood heights of streams entering the lake. The riparian interests affected are not so directly concerned with the maximum height to which the monthly mean elevations of the lakes are raised as with the frequency with which the lakes reach the levels which expose them to serious hazard of damage. As long as the frequency with which the lake levels rise above the flood levels is not increased by the construction of compensating works, or by the operation of regulating works, no damage can be considered to result from their construction or operation.

102. A study of the nature of the damage done by increasing the frequency of high lake levels shows that it is so widespread and diverse that compensation to the industries and individuals affected is out of the question. Communities have adjusted themselves to the lake levels that have actually existed, and cities and towns have built their sewage systems accordingly. The damages would not be met by merely paying for the flowage of such lands as might be actually flooded by the rise of lakes. It must be emphasized, moreover, that the inquiries did not bring to light all of the damages that would result from high water, for the reason that many of the citizens concerned and many of the responsible executives do not believe that a proposal to raise the high waters of the lakes will be seriously considered.

MAXIMUM DISCHARGE CAPACITY OF OUTLETS

103. LAKE SUPERIOR. The discharge capacity of the St. Mary's river, the outlet of lake Superior, has already been enlarged by the power canals at the falls to such an extent that little benefit would be secured by further enlargement.

104. LAKES MICHIGAN-HURON. The St. Clair river is nearly 40 miles in length, with a small and fairly evenly distributed slope, except at the Port Huron rapids at the head of the river. While at first glance there seems to be an opportunity to provide a considerable increase in discharge capacity by the enlargement of this contracted section detailed computations show that a by-pass canal if built with a depth of 35 feet and width of 700 feet, entailing the excavation of 7,800,000 cubic yards would increase the discharge capacity of the river by only 8,000 cfs., i.e., by about 4 per cent of its present capacity.

It may seem paradoxical that the one lake outlet that has been enlarged in recent years by the action of nature and man should be the least susceptible to further material enlargement. It will be noted, however, that the total enlargement accounted for to date effects an increase of only about 5 per cent to 8 per cent in the discharge capacity at high stages, and that this is the cumulative effect of actions taking place over a period of 35 years. As has been previously pointed out, the discharge capacity of the river is much curtailed in winter, but this is not the season when large discharges are desirable from the standpoint of regulation.

105. Lake Erie. A large increase of the discharge capacity of the Niagara river, at the outlet of lake Erie, can be secured, although at large cost, by the excavation through the rock sill at its head. The program for complete regulation hereinafter considered is based on an enlargement of the discharge capacity by 40,000 cfs.

106. St. Lawrence River. The discharge capacity of the St. Lawrence river is limited by seasonal conditions. For the purpose of testing a program for complete regulation, the limitations were taken as shown on plate 4. The reasons for these limitations are as follows:—

(1) The discharge at any time must not exceed the amount that can be passed through the enlarged channels without creating excessive currents for navigation and without requiring a head that would seriously reduce the head available for power. This limitation restricts discharge from lake Ontario to amounts varying from 223,000 cfs. with the lake at elevation 244.0 to 330,000 cfs. with the lake a little below elevation 248.

(2) The discharge must not create such stages in the St. Lawrence river as will cause serious damage to riparian property. The areas where such damage would occur are the lands bordering lake St. Francis and lake St. Louis. After the outlets of these lakes have been enlarged as a part of power development in the rapids below them, a maximum discharge of 330,000 cfs. should be possible.

(3) During the period in which the Ottawa river is in flood, in May and June, the maximum discharge should be limited to 300,000 cfs. in order to prevent excessive levels in lake St. Louis.

(4) The ice jams during the spring breakup, usually occurring in April, cause the highest rise of the water at Montreal. The higher the discharge of the St. Lawrence at such time, the higher the water is likely to rise. Large sums have been expended to prevent the flooding of the lower lying portions of the city at such times. The regulated discharge of the St. Lawrence has therefore been limited in April to an amount not exceeding the present discharge at the same stage.

(5) During the winter months of January, February, and March, the discharge capacity of the river will be reduced to an amount materially below that possible during open-river months. The successful operation of power plants on the river requires the creation and preservation of an ice cover wherever it can be secured at reasonable expense. Since the formation of an ice cover depends upon currents of sufficiently low velocities, the proper winter operation of the power plants requires that the discharge be restricted.

107. The further studies, made before adopting a definite program for the regulation of lake Ontario alone, has indicated some desirable modifications of these limitations,. but these modifications are insufficient to alter materially the results to be obtained from a comprehensive system of regulation of the Great Lakes.

MINIMUM PERMISSIBLE DISCHARGE THROUGH OUTLETS

108. The minimum discharges adopted in testing the programs for the complete regulation of the lakes were as follows:—

	Minimum Regulated Discharge	Minimum Natural Monthly Mean Discharge with Same Diversions (Summer)
St. Lawrence river	200,000	185,000
Niagara (including Welland canal)	176,000	167,000
St. Clair river (except when the natural discharge was less)	150,000	151,000
St. Mary's river	50,000	49,000

109. The minimum discharges for the St. Lawrence and the Niagara were set with a view to affording a reliable flow for power purposes. It is necessary to maintain an ample flow through the St. Clair and Detroit rivers to prevent the reversal of the current of the latter when storms raise its outlet into lake Erie, since such a reversal of flow would bring sewage-contaminated water to the water-supply intakes of the city of Detroit. Preliminary computations indicated that a minimum flow of 150,000 cfs. could be provided without substantial injury to the levels obtained by regulation. As later explained, an analysis of the results obtained indicates that some slight improvement in lake levels could be secured by fixing this minimum at 140,000 cfs. The minimum flow of 50,000 cfs. in the St. Mary's river is designed to maintain the full navigable depths in that river and to afford water for the existing power plants.

110. Low Water Discharge Required to Maintain Montreal Harbour Levels. The further study made before adopting a definite program for the regulation of lake Ontario alone, in connection with the improvement of the St. Lawrence, shows that a fixed minimum of 200,000 cfs. is insufficient to maintain the ordinary low levels of Montreal harbour during the summer and fall months. The actual monthly mean flow down the St. Lawrence has fallen below 200,000 cfs. but once during the navigation seasons of the past 65 years. This was in November and December, 1895, when the flow was 194,000 cfs. Even had a diversion of 8,500 cfs. occurred continuously during the past 65 years, the unregulated monthly mean flow down the St. Lawrence during the navigation season would not have fallen below 200,000 cfs. except during October, November and December, 1895, with a minimum flow of 185,000 in November and December of that year. Past records show that, for at least 70 per cent of the time, unregulated outflows down the St. Lawrence in September, October and November exceeding the following amounts are to be anticipated.

September	237,000 cfs.
October	228,000 "
November	222,000 "

It is shown in paragraph 210 of the main report that a diminution of the flow past Montreal reduces the water levels in the harbour at the rate of one foot for each 23,000 cubic feet per second. The adoption of a minimum flow of 200,000 might therefore be expected to reduce the ordinary low water levels in the harbour by about a foot during the fall months.

PROGRAM OF REGULATION TO SECURE MAXIMUM BENEFITS TO LAKE LEVELS

111. To determine the benefit to be anticipated from a complete system of regulation of the Great Lakes, a program was drawn up which was designed to secure such result, while maintaining the minimum outflows set forth in the preceding paragraphs. The lake levels and outflows that would have resulted

from its application from 1894 to 1925 were determined, the suitability of the system being tested by applying it also to the high and fluctuating discharges recorded between 1869 and 1876.

112. The computations were based on the supply of water to the various lakes that would have occurred had 8,500 cfs. been diverted continuously by the Chicago Sanitary District.

113. System Adopted. The program was designed to hold the lakes at the maximum safe levels whenever the water supply permitted. The " maximum safe stage " of each lake for each month of the year was determined from a study of their seasonal fluctuations in levels, as being the stage which, on the basis of levels reached during these months during the last twenty-five years, would be reached once in 8 years, as shown on table herewith.

TABLE 16.—"MAXIMUM SAFE STAGES" FOR REGULATION

Month	Superior	Michigan-Huron	Erie	Ontario
January 1	602·21	580·64	572·20	246·19
February 1	602·21	580·95	572·57	246·57
March 1	602·42	581·33	573·25	247·37
April 1	602·78	581·64	573·50	247·67
May 1	603·00	581·82	573·53	247·71
June 1	603·18	581·78	573·37	247·58
July 1	603·30	581·63	573·15	247·15
August 1	603·30	581·42	572·66	246·66
September 1	603·15	581·16	572·53	246·33
October 1	602·92	580·90	572·26	246·08
November 1	602·69	580·73	572·20	245·99
December 1	602·42	580·63	572·14	246·08

When the lakes were below these stages at the beginning of a month, the outflow to the St. Lawrence was so reduced that the expected supply to the lakes during the month would bring them to the maximum safe levels at the end of the month, if this result could be accomplished without reducing the outflow below the established minimum of 200,000 cfs.; if not, the outflow was set at this minimum. Whenever the levels of the lakes were above their maximum safe stages, the outflow was increased as necessary, up to the maximum discharge capacity, to bring them back to maximum safe stages. In either case the discharge between the lakes was regulated, within the maximum and minimum limits, to secure at low levels the best equalization of the channel depths at the present improvement planes, and at high levels the distribution of excess water which would minimize the hazard of flood damage.

114. During high stages, therefore, the lakes were kept as nearly as possible at equal stages from the standpoint of flooding, and in times of low water at equal stages from the standpoint of navigable depth. Between high and low water a transition zone is necessary. The upper limit of this zone was taken at the highest safe stage, and the lower limit at that stage giving equal navigable depths and a total storage in all the lakes of one million second feet months less than the highest safe stage.

115. The discharge capacity of the various channels and the allowable minimum flows limited the regulation so that very rarely was it possible to secure the condition of highest safe stage in all the lakes at the same time, and only occasionally could the same relative stage in all five lakes be secured. When the ideal condition could not be secured, the nearest approximation to it was obtained. If, for example, the capacity of the St. Clair river was inadequate

to discharge sufficient water to bring all the lakes to the same relative level, the maximum discharge possible was allowed in the St. Clair river; the Niagara river was regulated to give the same relative stages in lakes Erie and Ontario, and the St. Marys river was regulated to give the same relative stages in lakes Superior and Michigan-Huron. Because of the danger of flooding due to run off from the local drainage area, no lake was permitted to rise above its highest safe stage if it could be prevented without raising some lower lake to a relatively higher stage. For example, more than 200,000 cfs. minimum was frequently discharged from lake Ontario during the very low period of the last few years because, although the upper lakes were much below their highest safe stages, lake Ontario, with the minimum allowable flow coming in from lake Erie, and the probable local inflow, would exceed the highest safe stage and therefore be in danger of being flooded by a heavy local inflow unless more than the minimum flow was drawn out.

116. Because of the rapidity with which the relative levels of the lakes changed with respect to each other, and because to do so would have adversely affected navigable depths, no attempt was made to draw any of the lakes below their highest safe stage in order to have space available for water from lakes higher up which were above their highest safe stage, but could not be immediately equalized with the lower lakes because of the discharge limitations of the interlake channels. For example, if lakes Michigan-Huron and Superior were too high, but could not be equalized with lakes Erie and Ontario on account of the limited capacity of the St. Clair river, lakes Erie and Ontario were not drawn down on account of the excess supply in the Michigan-Huron and Superior, but were kept as nearly as possible at their highest safe stage.

117. Details of Computations. The effect of applying this system was computed by monthly periods on the form sheet shown herewith. It was assumed that at the first of each month the elevation of each lake could be determined from gauge readings. The probable local inflows for each lake were estimated from diagrams (plate 5) constructed from past records to give the probable inflow for the month as indicated by the local inflow to that lake during the past month. It was found by a study of the past supplies (one of which is shown on plate 6) that a month of large runoff was likely to be followed by another month of high runoff, and a month of low runoff by another of low runoff, and that from the diagrams much better results could be secured than by assuming that average conditions would probably occur in any given month. The outflows of the various lakes were computed which would give at the end of the month the best distribution of the storage if the probable inflow occurred, and the gates were set to give this outflow from the lakes during that month. With the known stage and storage at the beginning of the month, and these outflows, the storage and stage were computed which would have resulted at the end of the month, with the inflows which actually occurred in that month. The steps in detail are as follows:—

118. In line (1) was entered the elevation of each lake at the first of the month, and on line (2) the corresponding storage in each lake and the total storage above an assumed datum (two feet below the present improvement plane of the lake). Units of storage equivalent to the flow of a thousand second feet for a month were used, and flows were expressed in units of a thousand second feet. In line (3) were entered the probable net local inflow into each lake for the month and the probable total inflow as determined from the inflow diagrams. Line (4) is the sum of lines (2) and (3) and represents the probable storage at the end of the month if there were no outflow. In line (5) is recorded the

 (Continued on page 99)

TYPICAL COMPUTATION FOR REGULATION WITH COMPLETE CONTROL OF ST. CLAIR RIVER—JANUARY, 1870

——	Superior	Michigan-Huron	Erie	Ontario	Total
(1) Elevations of lakes at first of month	602·93	581·30	572·79	246·60	
(2) Storage in lakes at first of month	1,129	1,777	442	326	3,674
(3) Probable local inflow for month	−3	68	66	75	206
(4) Sum	1,126	1,845	508	401	3,880
(5) Total storage danger stage end of month					3,062
(6) Outflow to give danger stage					818
(7) Limits of outflow from system—Maximum					211
(8) Minimum					200
(9) Outflow selected					211
(10) Desired distribution of storage	1,115	1,781	435	338	3,669
(11) Desired net outflow	11	64	73	63	
(12) Desired gross outflow	11	75	148	211	
(13) Limiting outflow—Maximum	124	222	260	211	
(14) Minimum	50	150	176	200	
(15) Outflow adopted—Net					
(16) Gross					
SUPERIOR–MICHIGAN–HURON SYSTEM					
(17) Total storage plus inflow	1,126	1,845			2,971
(18) Trial outflow					150
(19) Total storage, end of month					2,821
(20) Storage in system at danger stage					2,408
(21) Desired distribution of storage	1,027	1,734			282
(22) Outflow—Net	39	111			
(22) Gross	39	150			
SUPERIOR SYSTEM					
(24) Total storage plus inflow	1,126				1,126
(25) Trial outflow					50
(26) Total storage, end of month					1,076
(27) Storage in system at danger stage					950
(28) Desired distribution of storage	1,076				1,076
(29) Outflow—Net	50				
(30) Gross	50				
MICHIGAN–HURON–ERIE SYSTEM					
(31) Total storage plus inflow	50	1,845	508		2,403
(32) Trial outflow					176
(33) Total storage, end of month					2,227
(34) Storage in system at danger stage					1,826
(35) Desired distribution of storage		1,791	436		
(36) Outflow—Net		54	72		
(37) Gross	50	104	176		
MICHIGAN–HURON SYSTEM					
(38) Total storage plus inflow	50	1,845			1,895
(39) Trial outflow					150
(40) Total storage, end of month					1,745
(41) Storage in system at danger stage					1,458
(42) Desired distribution of storage		1,745			1,745
(43) Outflow—Net		100			
(44) Gross	50	150			
ERIE–ONTARIO SYSTEM					
(45) Total storage plus inflow		150	508	401	1,059
(46) Trial outflow					211
(47) Total storage, end of month					848
(48) Storage in system at danger stage					654
(49) Desired distribution of storage			474	374	848
(50) Outflow—Net			34	27	
(51) Gross		150	184	211	
(52) Storage, first of month	1,129	1,777	442	326	3,674
(53) Local supply factors	9	118	65	62	254
(54) Sum	1,138	1,895	507	388	3,928
(55) Outflow used—Net	50	100	34	27	211
(56) Storage, end of month—Approximate	1,088	1,795	473	361	3,717
(57) Stage, end of month—Approximate	602·82	581·34	573·07	247·02	
(58) Discharge, end of month—Approximate				215	
(59) Discharge, first of month				211	
(60) Mean discharge				213	
(61) Storage correction				2	
(62) Storage, end of month—Corrected	1,088	1,795	473	359	3,715
(63) Stage, end of month—Corrected	602·82	581·34	573·07	247·01	
(64) Outflow used—Gross	50	150	184	213	

total storage in the lake system if all lakes were filled to the highest safe stage for that month. Line (6), the difference between lines (4) and (5), is the outflow which would be necessary from the lake system to have just sufficient storage in the system at the end of the month to bring all the lakes to their highest safe stage. In line (7) is entered the maximum flow of the St. Lawrence river for the elevation of lake Ontario at the beginning of the month, as indicated by plate 4, and in line (8) the minimum flow for the scheme of regulation under consideration. A comparison of the figures in lines (6) and (7) shows that it is not possible to draw all the lakes down to their highest safe stage in this month, and therefore the nearest possible result to this will be obtained or the outflow selected, line (9), will be the maximum possible, as entered in line (7). If the figure in line (6) had been less than 200, the minimum flow of 200 would have been used in line (9), and if between the maximum and minimum, the outflow in line (6) would be used in line (9).

119. In the last column of line (10) is entered the total storage remaining in the system at the end of the month if the outflow selected (211 thousand second feet) were withdrawn. This is distributed between the lakes according to diagrams as plate 7, one for each month, which show the storage in each lake which, for any given total storage, will bring all of the Lakes to the same relative stage. From plate 7, with 3669 as the total storage, is found the storage in each of the lakes shown in the other columns of line (10). The values of the storage corresponding to the critical points on the storage distribution curves are given in Table 17. All curves go through the origin of co-ordinates as plate 7. The values of net outflow from each of the lakes, line (11), which will bring about the desired distribution of storage, are the difference between the value in lines (4) and (10), and line (12) gives the gross outflow, or the summation of net outflows. In lines (13) and (14) are entered the maximum outflow possible in the interlake channels with the enlargements and control works and with the stages of the various Lakes the first of the month. In case of ice retardation in the St. Clair River, the same per cent of reduction was applied to the maximum unobstructed discharge with the enlargements as occurred in the natural river. In line (14) are entered the minimum allowable flows, for the system of regulation under consideration.

120. By comparing the values in lines (12), (13), and (14), it will be seen that to secure the desired distribution of storage, a flow less than the minimum allowable would be necessary out of lakes Superior, Michigan-Huron, and Erie, and lines (15) and (16) cannot be used in this case. It is necessary therefore to secure as nearly as possible the desired distribution with the limitations of outflow. The difference between the desired and allowable flows is greatest in the Michigan-Huron outflow, and it therefore is probably a controlling relation. Lines (17) to (23) treat lakes Superior and Michigan-Huron as a separate system, in the same manner as the whole lake system was treated in lines (14) to (14), using the appropriate scale of ordinates on the right side of the storage distribution diagram (plate 7). The values in line (17) are the individual storages of the lakes of the Superior-Michigan-Huron system from line (4), and the inflow from lakes above (in this case zero), the sum of them being entered in the last column. The value in line (20) has no significance in this case, but has in cases where the storage in the system is near that required to fill all the lakes to their highest safe storage. The values in line (23) show that to bring Michigan-Huron and Superior to the same relative stage at the end of the

month would require a flow less than the minimum allowable out of Lake Superior. Lake Superior is therefore treated as a separate system in lines (24) to (30), and a trial computation made in lines (31) to (37) shows that if lakes Michigan-Huron and Erie are brought to the same relative elevation with the minimum outflow necessary from Lake Superior, the outflow from Lake Michigan would be below the allowable limit. Lakes Michigan-Huron are therefore treated as a separate system in lines (39) to (44), using the minimum allowable outflow, and lines (45) to (51) show that with this outflow lakes Erie and Ontario can be brought to the same relative stage within the limitations of outflow from lake Erie. To obtain the nearest possible result to the highest safe stage in all the Lakes with the probable inflows for the month and with the flow limitations of the interlake channels and the St. Lawrence river, it is therefore necessary to take the minimum allowable flow out of Lakes Superior and Michigan-Huron and 184,000 second feet from Lake Erie, and the maximum possible out of lake Ontario. The regulating gates would therefore be held during the month to give flows of 50,000 second feet from Superior, 150,000 second feet from Michigan-Huron, 184,000 second feet from Erie and 211,000 second feet from Ontario. With these outflows, and the local inflows entered in line (53) which actually occurred during the month, the storage in each lake and the stage at the end of the month is computed on lines (56) and (57). A correction is made in lines (58) to (62) on account of the increase which is possible in the outflow of lake Ontario due to the increase in stage in that lake during the month. In lines 62) to (64) are entered the storage and stage at the end of the month and the gross outflow from all the lakes.

121. The example given above represents one of the more difficult cases and involves much more computation than the average. Large-scale diagrams were used to show the storage distribution relations for the various months, of which plate 7 illustrates the principle. The numerical work contains a very complete series of checks which reduce the probability of error to a minimum.

122. Results Secured. The lake levels and outflows resulting from this system of regulations are given in tables 9-12 and are shown graphically on plates 8 and 9. The results are best summarized, however, on plates 10 and 11, which give the relative length of time at which the levels during the navigation season, and the discharges throughout the year, would be realized.

123. Effects on Lake Levels. In evaluating the beneficial effects of regulation on lake levels, it is misleading to deal with the absolute minimum levels reached. Present bulk-cargo lake commerce, with its short voyages and highly organized management, is benefitted by a rise in the mean levels of the lakes to almost as great a degree as by a rise in the minimum levels; and even commerce entering the lakes from the sea, as a consequence of the improvement of the St. Lawrence, will not be vitally concerned with low levels which rarely occur. The basis of comparison adopted is therefore the level below which, on the basis of past experience a lake will not fall during more than 2 per cent of the time.

124. The following tabulation gives, on this basis, the range of levels of the various lakes, during the navigation season, which would be secured by the program of regulation described, during the period from 1894 to 1925, as compared with the range, on the same basis, that the lake levels would have had

during the same period with the outlets in their present condition and with the present diversions (and a total diversion of 5,000 cfs. through the Welland Canal):—

Lake	Regulated			Unregulated		
	Highest	Low	Range	Highest	Low	Range
			feet			feet
Superior	603·7	601·3	2·4	603·8	601·0	2·8
Michigan-Huron	582·5	580·1	2·4	581·8	578·3	3·5
Erie	574·3	571·5	2·8	573·8	570·5	3·3
Ontario	248·6	245·8	2·8	248·4	244·2	4·2

125. Since the levels of the lakes can be raised equally well by compensating works to the maximums attained by this system of regulation, without increasing the present range between maximum and low stages, the advantage of regulation, from the standpoint of navigation, lies in the reduction in the range of stage. This is as follows:—

Superior	0.4 feet
Michigan-Huron	1.1 "
Erie	0.5 "
Ontario	1.4 "

126. Taking the whole period from 1860 to 1925, on the assumption that the maximum stages under regulation would occur in 1870 or 1876, the *total* fluctuation of stage in the regulated and unregulated condition is:—

Lake	Total fluctuation	
	Regulated	Unregulated, with present diversions and outlets
Superior	3·41	3·54
Michigan-Huron	3·52	4·92
Erie	3·29	3·53
Ontario	3·83	5·54
Weighted average	3·47	4·35

127. In paragraph 68 it was shown that a study of the mass curve of supply indicated that a minimum outflow of 200,000 cfs. could be maintained with a fluctuation of 2.0 feet on the lakes. The difference between this figure and the average fluctuation of 3.47 resulting from the detailed program of regulation, is due to the limitations imposed by the discharge capacities of the outlet.

128. Effect on outflow. An examination of plate 11 shows that the result of applying the program would have been to hold the outflow down the St. Lawrence to the minimum of 200,000 cfs. for nearly half the time in order to build up lake levels. The unregulated flow falls below 200,000 cfs. for a very small percentage of the time, but exceeds that figure most of the time. A detailed analysis of the effects of the regulated flows on the low water levels of Montreal harbour during the period 1913 to 1924 confirms the general analysis given in par. 110 that the program would lower the ordinary low water levels by approximately one foot. It is apparent, moreover, that the results secured would be unfavorable rather than beneficial from a power standpoint. A similar condition would be created in the Niagara river by the scheme studied.

DESIGN AND COST OF REGULATING WORKS

129. The design of regulating works that will satisfactorily meet ice conditions in the Niagara river, and will accomodate the great volume of shipping in the St. Clair river, offers many complications. The designs forming the basis of the estimates of the cost herein presented are intended to afford only a reliable indication of the minimum cost, which might be increased materially by elaborations deemed necessary to meet the unusual requirements.

130. Works in St. Clair River. Because of the delay which locks would cause to the heavy traffic on the St. Clair and Detroit rivers, it is desirable to control the flow in these rivers by some means in which they are not required. The studies and estimates of cost indicate that sufficient control may be obtained by channel contractions to secure substantially as good results in lake control at about the same cost as would be possible with locks and dams. The method of restricting the outflow in the St. Clair river was to select a location where the river was divided into two or more channels by islands, placing control gates across all but one channel, thus allowing the navigation to pass unobstructed through this channel. By closing the gates the entire flow could be forced through the one channel, which would restrict the flow. Where natural divisions in the river were absent or insufficient, they were artifically constructed by longitudinal dikes.

131. Point Edward By-pass. To provide additional discharge capacity in the St. Clair river, a by-pass channel was provided around the Port Huron rapids at the town of Point Edward, where the St. Clair river leaves Lake Huron. The channel would extend from the Point Edward range lights at the head of the St. Clair river to Sarnia bay, and along the west side of this bay entering the St. Clair river at Bay point. It would have a length of about 8,000 feet, a bottom width of 700 feet, and a depth of 35 feet. Investigation showed that a greater increase in size would not secure sufficient increase in St. Clair river flow to justify the additional cost. The control works would consist of concrete floor, piers, and abutments with Stoney sluice gates. As it would be necessary to provide railroad and highway access to the docks to the west of the canal, the control works would be combined with a railroad and a highway bridge. With all the gates open, this by-pass would increase the flow in the St. Clair river by about 8,000 cfs. The total cost of the canal and control works is estimated at $2,770,000.

132. Stag Island Contraction. The first contraction works would be located at Stag Island, near the town of Marysville, about 8 miles below Lake Huron. The length of Stag Island is insufficient to give the desired reduction in flow, and dividing dikes would be extended from the upstream end of the island to opposite the town of South Park, and downstream from the lower end of the island to Oakland Dock, about 2,400 feet below the mouth of Pine river, near the town of St. Clair, the total length of river thus divided being about 46,000 feet, or slightly more than 8 miles. The control gates would be located across the channel east of Stag island, and were similar to those on the Point Edward Canal. Navigation would pass through the west channel, which would have a minimum width of 1,080 feet. To prevent the enlargement of this channel by the higher velocities which would result from closing the regulation gates, rock sills 10 feet wide and 3 feet average thickness could be placed on the bottom extending across the river at 100-foot intervals. The Stag island control works as thus outlined, with no deepening of the present channel would increase the stage necessary in Lakes Michigan-Huron for a discharge of 180,000 cfs. by 1.54 feet and would cost about $10,120,000.

133. Woodtick Island Contraction. The second control would be at Woodtick Island, near Marine City, about 22 miles below lake Huron. At this point the flow to the east of the island is so small that closing it off would cause little effect, and a dividing dike would be built in the west channel extending the entire length of the control works, from a point opposite the center of Marine City to a point opposite the plant of the Michigan Sault Manufacturing Company, a distance of about 11,000 feet. Two control gate structures would be necessary, one extending from the dike to Woodtick Island and the other across the channel east of this island. These would be similar in construction to those designed for the Point Edward Canal. The channel to the west of the dividing dike would be protected against enlargement in the same manner as proposed for Stag island. The minimum width of the navigation channel is 1,040 feet. The cost of this control is estimated at about $3,730,000 and the effect in the lake would be about 0.51 foot.

134. Contraction at Delta. Near the town of Algonac, the St. Clair river divides into a number of mouths which pass through a delta into lake St. Clair. Where the river divides into two channels, control works would be built across one branch by which more water could be forced through the other (the south channel), thus increasing its slope and reducing the total discharge of the river. Since this channel is somewhat narrow, but must carry all the through navigation of the St. Clair river, and because of the easily eroded character of the soil, the amount of water forced through this branch would be limited to that which would produce a mean velocity of 3 feet per second. To prevent enlargement, sills of loose rock, averaging 10 feet wide and 3 feet thick, would be placed across the channel at 200-foot intervals. This mouth contains a bad bend, which would be cut off by a channel of 600 feet bottom width. The estimated cost of the works is $6,150,000 and their effect on the level of Lakes Michigan-Huron is 1.25 feet.

135. Since all the other mouths are cut off from Lake St. Clair by bars which have formed at their outlets into this lake, the control works across their upper end would cut off the access of boats to them. A 200-foot channel would therefore be excavated through one of these bars to let navigation pass up through one of these mouths and from it into the others which are cut off.

136. Summary, St. Clair River. In summary, the contraction works designed for the control of the St. Clair river for complete regulation, and their effectiveness in feet of fall, are as follows:—

Location	Estimated cost	Increased head
Stag Island	$10,120,000	1.54
Woodthick Island	3,730,000	.51
Delta	6,150,000	1.25
Total	$20,000,000	3.30

The works could be operated to reduce the outflow from lake Huron by roughly 30 per cent when so desired.

137. The total length of the contracted channels in this scheme of control, counting the delta channel as 7 miles in length, is 18 miles, and the success of the scheme depends on preventing an enlargement of their sections with the increased current velocities created by the contractions. The estimates provide for what is regarded as ample protection of the bed against scour below a depth of 30 feet, but there is no precedent for determining the extent to which this protection would have to be carried.

138. Alternative Plan of Dam With Locks. An alternative is to construct control gates with locks at a suitable point in the river. Since a minimum flow of approximately 140,000 cfs. must be maintained, the gates need not entirely close the river, and a navigable pass could be left through which the lighter shipping could pass downstream. It is not believed that the lake cargo freighters (which are normally carrying their full loads downstream) could use such a pass, and the locks should be sufficient to pass all vessels of that class. In 1925, the total number of steam-vessel passages through the St. Marys falls canals, exclusive of tugs, yachts, etc., was 18,718. The number of vessel passages through the Detroit river during the same year was 18,146, exclusive of sand carriers and passenger steamers, tugs, yachts, etc. The lock capacity provided in any works in the St. Clair river should be at least equal to that which has been found necessary at the St. Marys falls canals, which is a capacity to pass six lake freighters simultaneously. Three double-length locks would therefore be required. The cost of the locks, approaches, dam and pass is estimated at not less than $30,000,000.

139. The average time required in 1925 for passage through the United States canal, including one lock and $1\frac{3}{4}$ miles of canal, was 1 hour and 9 minutes. The average time, up and down bound, to pass through the canal is 17 minutes. The average time of lockage only, including delays, is therefore 52 minutes. The average freight carried per vessel passage was 4,370 tons, and the average rate per ton-mile was 1.08 mills. Assuming that a delay of 52 minutes is equivalent to 9 miles of travel, the average cost per vessel passage, light and loaded, in terms of revenue producing capacity of the vessel, becomes $42, and for 18,146 vessel passages $762,000 per year. The economic loss would increase with increasing traffic on the waterway. This economic loss would justify heavy maintenance costs on an open-channel scheme. Despite the uncertainty of the latter, it has been considered advisable to present it as a basis for regulation works.

140. Works in Niagara River. The works designed for controlling the outflow of lake Erie were located at the upper end of the Niagara river at Buffalo. A longitudinal dike would be built in the river, extending from Bird island, opposite the Buffalo Water Works pumping station, down the river to Ferry street, a distance of about 7,000 feet. It would be roughly parallel to the present dike along the west side of the Black Rock canal and would be on the average about 700 feet farther out in the river. It would reduce the minimum width of the river from approximately 1,600 to 1,000 feet. At the upper end of this dike, Stoney gate control works would be located by means of which the flow through the channel inside the dike could be shut off, thus reducing the flow out of lake Erie. To increase the outflow, 4,300,000 cubic yards of rock from the controlled channel and from Limekiln reef opposite its upper end would be excavated. The maximum hold-back capacity of this control on lake Erie as compared with present conditions would be 2.50 feet, and the increase in discharge which is possible as a result of the excavation is 40,000 cfs. The cost was estimated at $13,650,000.

141. Much of the excavation could be done more economically by using the longitudinal dike as a cofferdam. However, it would not be possible to entirely close off the entire area at once, as this would raise Lake Erie toc high; but another cofferdam could be built first between the location of the longitudinal dike and the bank, and a channel excavated behind this. This channel could then be opened, the longitudinal dike built, and the rock between the first cofferdam and the longitudinal dike excavated.

142. Summary. In summary, the estimated cost of the works required for the program of complete regulation is as follows:—

Niagara river	$13,600,000
St. Clair river control works	20,000,000
Point Edward by-pass	2,800,000
Total	$36,400,000

143. It is of interest to note that the estimated cost of the works proposed by the Engineering Board of Review for the Chicago Sanitary District, as given by Mr. John R. Freeman in an appendix to that report, is as follows:—

Works in Niagara river	$ 8,174,000
Works in St. Clair river	25,312,000
Total	$33,486,000

These estimates do not include, however, certain protective works in the Niagara river, nor the enlargement of its discharge capacity required for effecting its regulation in the lower range of levels now found necessary, and the provision made for navigation in the St. Clair river may be criticized as inadequate.

144. Comparative Cost of Compensating Works With Dredging. In comparison, the cost of securing the same increase in the navigable depths of the channels and harbours of the lakes affected, by compensating works supplemented by dredging, is hereinafter shown to be as follows:—

Cost of compensating works	$ 3,400,000
Additional cost of dredging lake channels	5,000,000
Additional cost of dredging harbours	5,000,000
Total	$13,400,000

145. Conclusions. In view of this showing, the construction of regulating works as a means for improving navigation is regarded as economically unjustifiable. It therefore has been considered unnecessary to give to the designs on which the above estimates are based the searching study that would be required if their construction was to be recommended.

146. Improvements Possible in the Program for Complete Regulation. —In view of the disappointing results attained by the program for regulation that was tested, a study was made of the possibility of a program that would yield better results. It is found that the "maximum safe stages" chosen on Michigan-Huron and Erie in the preceding study were somewhat too conservative, and that the levels on Michigan-Huron could have been raised 0.3 foot, and on Erie, 0.4 foot, without raising the regulated high-water levels above the natural high-water levels. This would not change the range in stage, except in so far as the increased discharge capacity due to the higher levels might offer the means for a reduction. Analysis of the critical periods shows that the effect on the range would be trifling. A reduction in the capacity artificially provided in the Niagara would become permissible, but further works in the St. Clair river would be required to secure the increased stages, the saving on the one hand and the cost on the other about balancing each other. The minimum discharge of 150,000 cfs. set for the St. Clair River (except when in winter the natural discharge is less) is at a few short critical periods a little more than is necessary to afford the minimum discharge set for the Niagara; but a reduction in flow during these short periods would effect but a trifling improvement in the

low levels of Michigan and Huron. By reducing the minimum set for the discharge of the St. Mary's River the range of stage on lake Superior could be decreased at the cost of increasing the range on Michigan-Huron, but no material advantage would result therefrom.

147. An entirely independent program of regulation, based on fixed rule-curves for determining the regulated monthly outflows, was tested over a portion of the period and found to give substantially the same results as those secured by the more elaborate program that has been described.

148. Finally, it may be noted that the results secured are not out of line with those predicted from the scheme of regulation advanced in the report of the Engineering Board of Review for the Sanitary District of Chicago. Putting the upper limit of the normal range of levels suggested in that report at the flood levels found in paragraph 100 of this report, the normal regulated low-water levels of the lakes under the two schemes become as follows:—

Lakes	Regulation proposed by Engineering Board of Review for Chicago Sanitary District	Complete program of regulation studied in this report (corrected as in par. 144)
Superior	601.1	601.0
Michigan-Huron	579.7	580.4
Erie	572.4	571.8

The higher level secured in the one case on lake Erie is at the expense of a lower level on lakes Michigan-Huron. The comparison is not satisfactory, since it compares " normal " stages, which may not mean the same thing in the two cases; but this Board has not the detailed tabulation of the levels under the program of regulation had in view by the engineers for the Sanitary District on which to base a more exact comparison. While the program indicated by them afforded a higher minimum flow to the Niagara River, it did not take into consideration the limitations that must be imposed on the discharge through the St. Lawrence.

149. The program for regulation was based, as is usual, on maintaining a fixed discharge each month, determined by the lake levels at the beginning of the month. It has been thought that materially better results could be secured if the discharge were varied during the month in accordance with the lake levels that actually developed during the month. An examination of a few critical periods indicates, however, that the improvement would be slight. The difference between the actual and expected supplies may indeed result, in rare cases, in lake levels at the end of a month differing as much as six inches from those predicted at the beginning of the month. The extreme high levels are, however, the result of a period of high supply lasting for several months, during all of which the program for regulation would provide the maximum allowable discharge. The best that could be done by adjusting the discharge to the levels during a month would be the starting of the maximum discharge say two weeks earlier. Since high discharges are put in effect as the lake levels approach the maximum safe stages, the gain by starting the full maximum permissible discharge two weeks earlier would be very small. Similarly, extreme low levels occur at the ends of long periods of low supply, during which the regulated discharge is held down each month to the permissible minimum in any event. The actual experience with the regulation of lake Superior confirms the conclusion that no material improvement could be realized by the refinement of changing the discharge during a month.

150. Regulation with Partial Control of the St. Clair River.—In view of the great cost of works in the St. Clair river, required to effect the degree of control over its flow, necessary to the complete program of regulation hereinbefore described, and the uncertainties as to the cost of preventing the enlargement of the many miles of contracted channel in the St. Clair river contemplated by the design, with consequent loss of effectiveness, a program of regulation was worked out which could be put in effect with less extensive works.

151. The works in the St. Clair river, contemplated in the modified scheme, are control structures at Stag island (8 miles below the head of the river) and at Woodtick Island (22 miles below the head of the river). The works at Stag island are similar to those proposed at this site for complete control (par 130), but the longitudinal dike extends only to the ends of the natural bar extending up and down stream from the island, giving a total length of 17,000 feet of contracted channel. Their estimated cost is $2,560,000 and their effectiveness, with the gates closed, is measured by 0.50 foot of head on lake Huron. The works at Woodtick island are identical with those proposed for complete control (par. 131). Their estimated cost is $3,730,000 and their effectiveness is measured by 0.51 foot on lake Huron. The total cost of the works is therefore $6,290,000 and their total effectiveness is 1.01 feet on lake Huron. The closinng of the gates at both works would reduce the discharge capacity of the St. Clair-Detroit rivers by roughly 10 per cent.

152. The contemplated works for the Niagara River are similar to those considered for regulation with complete control of the St. Clair river (see paragraph 140), but with less outlet enlargement. The enlargement proposed requires the excavation of 2,100,000 cubic yards and gives an increase in discharge capacity of 25,000 cfs, as compared with 4,300,000 cubic yards and 40,000 cfs in the complete control scheme. The cost is estimated at $8,575,000. These works if continuously closed would raise lake Erie 1.25 feet.

153. The program of regulation is based on the same limitations as to minimum flows and flood levels as governed that for complete regulation. The operation of the gates was, however, based on set rule curves, instead of budgeting the water between the lakes. These rules were in the form of diagrams as shown on plates 12 to 15. Plate 12, the diagram for lake Superior outflow, gives the number of gates in the control works at St. Mary falls which should be opened during each month for the various stages in the lake on the first of the month, and curves showing the discharge which such gate openings would produce. Plate 13 gives the rule by which the gates of the Stag and Woodtick Island controls in the St. Clair river would be regulated, and diagram showing the discharge of the St. Clair river for the various stages in lakes Huron and Erie, with all the gates of these two controls both open and closed. The same per cent of retardation from ice was assumed for the controlled flow as existed for the natural flow. Plates 14 and 15 give the discharge to be allowed during the month for the various stages on the first of the month in the Niagara and St. Lawrence, respectively.

154. This system of regulation materially changes the outflow of lake Superior, reducing the flow in the early part of the year and substantially increasing it in the fall. This causes the lakes to rise more rapidly in the early part of the year, and thus produces greater depths in the lake; and the increased flow in the fall reaches lakes Michigan-Huron at a time when their levels are beginning to drop, and thus tends to keep them up. Looking from a different angle, it may be said that the heavy inflows into lake Superior take place later

in the year than in the other lakes. By reducing the outflow during the first part of the year lake Superior is made to rise more nearly synchronously with the other lakes, and by discharging larger quantities in the latter part of the year, the falling levels are also more nearly synchronized. This tends to keep the depths of water in the navigation channels of all the lakes more nearly the same.

155. The application of the rule curves of the St. Clair river, is such that over long periods of years the gates remain closed, except for an adjustment period immediately after completing the work. Two of these long periods are 1863 to 1874, inclusive, and 1889 to 1903, inclusive, 12 and 15 years, respectively.

156. Results Secured by Regulation with Partial Control of the St. Clair River. The lake levels and discharges secured by this less complete control are shown in tables 9 to 12, and are shown graphically on plates 16 to 19. The results are summarized in the duration curves shown on plates 10 and 11.

157. Eliminating as before the low levels occurring less than 2 per cent of the time, the range in level during the navigation seasons in the period between 1894 and 1925 would have been as follows, had the system been in effect during that period:—

Lakes	High	Low	Range
Superior	603·4	600·6	2·8
Michigan-Huron	582·3	579·2	3·1
Erie	574·5	571·3	3·2
Ontario	248·0	244·6	3·4

158. These ranges compare as follows with those heretofore found (par. 124) for complete regulation and for the unregulated flow through the present outlets:—

Lakes	Range in stage, 1894–1925		
	With complete regulation	With partial control of the St. Clair River	Unregulated, with present outlets
Superior	2·4	2·8	2·8
Michigan-Huron	2·4	3·1	3·5
Erie	2·8	3·2	3·3
Ontario	2·9	3·4	4·2

159. As compared with the results secured by compensating works, the system of regulation with the works proposed for the partial control of the flow of the St. Clair river would afford, therefore, but 0.4 foot gain in the low levels on lakes Michigan-Huron and 0.1 foot on Erie, if the high levels were raised to the same elevation in the two cases.

160. As in the case of complete regulation this system would increase somewhat the minimum discharge of the Niagara and St. Lawrence rivers, but would prolong the period during which low discharges occur. The irregularity introduced in the flow of these rivers would not be nearly as far reaching as in the

case of the complete system of regulation. The effect on the ordinary levels of Montreal harbour, as tested from 1914 to 1924 would be a reduction of a few tenths only in the harbour levels. A slight modification of the rule curves would remedy this effect.

161. Works in St. Clair River only. The Board has considered a suggestion made by Mr. M. G. Barnes, Chief Engineer, Division of Waterways State of Illinois, that works similar to those just discussed be constructed in the St. Clair river only, for the purpose of raising the low water stages of lakes Michigan-Huron, without raising the high-water levels correspondingly. The control over the flow in the St. Clair river secured from the works suggested would not be far different from that secured from those proposed for the modified program of regulation pust considered. If these works were operated as proposed in that program to hold back water when it could be spared from lake Erie, the gain in the levels of Michigan-Huron could not exceed that found from the modified program described, amounting to a few tenths only in excess of the gain that can be provided by compensating works. It must be recollected that to raise lakes Michigan-Huron one inch in a month, it would be necessary to hold back a flow of 40,000 cfs. during that period, and that this would lower the level of lake Erie by 4½ inches.

162. The present natural retardation of the flow of the St. Clair and Detroit rivers by ice gorging in winter serves to raise the levels of lakes Michigan and Huron; and, since it occurs just prior to spring rise in Erie, does not reduce the minimum navigation levels on the latter. Since the amount of winter retardation varies from year to year, the thought has occurred to engineers who have given lake levels long study, that it would be useful to provide artificial works to insure this retardation when nature fails to effect it. A study of the discharges of the St. Clair river under the program for complete regulation, shown on plate 8, discloses that this is substantially the effect brought about by that program. But to bring it about it is necessary to construct very elaborate and expensive works on the St. Clair. The results that can be secured from less comprehensive works, which will at the same time afford free channels of the capacity required for navigation, are indicated by results predicted under the modified program of regulation hereinbefore discussed, and would amount to a gain in the levels of lakes Michigan and Huron exceeding by only a few tenths of a foot the gain that can be provided by fixed compensating works.

163. Combined Regulation of Lakes Erie and Ontario. An attempt was made to devise a program for the regulation of Lake Erie that could be put in effect in conjunction with the required regulation of lake Ontario to the mutual advantage of the levels and outflows of the two lakes. It was found, however, that the program arrived at after considerable study increased the maximum range of stage on lake Erie, and the fluctuations in its discharge, while at the same time the regulation of lake Ontario that could be secured with the altered flow from lake Erie was not as beneficial as that which could be secured with the natural flow. The reason for this seeming anomoly is not difficult to discover. The present natural discharge from lake Erie to lake Ontario increases gradually as lake Erie rises, and decreases gradually as it falls. Extreme fluctuations in Erie are therefore checked, while at the same time lake Ontario is not subjected to violent changes in inflow. It is not difficult to work up a program that would improve the present situation during a given sequence of unusually high or low supplies to the two lakes; but if such extremes happen to occur in a different sequence, the program is apt to aggravate rather than to

improve the situation. To devise a program that will best meet all extremes that have occurred is no small task; and it is well to recollect that such a program might not meet the combination of extreme conditions that may occur in the future. In any event, the only possible way by which the present fluctuations in the levels of lake Erie can be reduced is by intensifying the fluctuations in discharge, and such course cannot serve otherwise than to render the regulation of Ontario more difficult in the long run and to decrease the benefits derivable from the regulation of that lake.

164. Regulation of Lakes Michigan-Huron and Erie for the Benefit of Power Development. The schemes for regulation of these lakes heretofore considered have been directed primarily to reducing the range of fluctuation of lake levels, in order to raise the low levels for the benefit of navigation without raising the high levels to the detriment of the cities and towns on the lake shores. It has been seen that the results attainable are small in relation to the cost of the works necessary to produce them. While it is true that the systems proposed effect at the same time a small increase in the absolute minimum flow available in the power reaches of the Niagara and the St. Lawrence, yet the systems greatly prolong the period during which low discharges occur.

165. A study of the levels and outflows resulting from the program of complete regulation, shown on plates 8 and 9, indicates that during the period of 32 years covered by the diagrams, a minimum flow of about 215,000 or 220,000 cfs. could have been maintained into the St. Lawrence (except during such times in winter as such a draft might be inadvisable due to ice conditions), and a minimum flow of 186,000 cfs. maintained out of lake Erie (Niagara River and Welland Canal combined) without causing a greater fluctation in the levels of the Lakes than actually occurred in their unregulated condition. Under such a program the benefit to navigation on the Great Lakes, as compared with the benefits to be secured from compensating works, would have been nil. The advantages, and disadvantages, to power on the St. Lawrence would have been roughly as follows:—

(1) For about one-third of the time, during which the natural flows ranged from 186,000 to say 217,000 cfs. the flow would have been increased to 217,000 cfs.

(2) For another third of the time, during which the natural flows ranged from 217,000 to 240,000 cfs., the flow would have been decreased to 217,000 cfs.

(3) For the last third of the time the flows would have been in excess of the capacity of the power plants in either case.

166. Had the St. Lawrence river been fully developed for power, the output that might be classed as strictly primary would have been increased by about 15 per cent, but the total kilowatt hours that could have been delivered from hydro-electric plants with installed capacity to utilize the natural mean flow of the river would not have been increased materially if at all.

167. The redistribution in flow would be of doubtful benefit to Montreal harbour. Taking the critical month of October, it is found that a flow of 217,000 cfs. would raise the extreme low harbour levels occurring 10 per cent of the time, but would depress the levels occurring the remaining 90 per cent of the time.

168. That any program of regulation of the Great Lakes must prolong the periods of lower outflow is not generally appreciated or even suspected; but is an inevitable consequence of the restricted discharge capacity of the outlets. An ordinary storage reservoir has a spillway capacity sufficient to discharge all

of the water that reaches it in floods, so that water can be stored at pleasure. The outlets of the Great Lakes, both separately and as a whole, are insufficient to discharge the water which reaches the Lakes during periods extending over several months in each year, and enlargements possible with the expenditure of millions of dollars will increase the capacity but by a relatively small degree. To maintain lake stages within their present limits of fluctuation it is necessary, therefore, to spread an increased discharge over a range of stage so wide that it infringes on the beneficial storage resulting from the present outlet regime. The storage of water by regulation must be limited to periods when all or most of the natural outflow has some present or prospective beneficial use. But the water so stored can be put to beneficial use only if the subsequent supply is below normal. If the subsequent supply is above normal the stored water must be discharged at an accelerated rate, and has no beneficial use.

169. Program Directed to Raising Lake Ontario Levels. Power on the International Section of the St. Lawrence might also be benefited by a different program of regulation directed toward reducing the fluctuations of lake Ontario so that it could be held continuously at high levels. The head on the upper power plants could therefore be increased and better conditions realized for maintaining the winter flow without creating current velocities incompatible with the maintenance of an ice cover. Such a program would, in effect, eliminate lake Ontario from the reservoir system of the Lakes, but inasmuch as its area is but about 8 per cent of the total lake area, its loss would not curtail seriously such beneficial effects of regulation as may at some future time be regarded as worth their cost. Preliminary computations indicate that a program of regulation based on these lines is practicable.

170. Regulation of Lake Erie for Niagara Power. The regulation of lake Erie for the primary purpose of restributing the daily flow of the Niagara to the best interest of the scenic beauty at the Falls and power resources of the river has been suggested, but this phase of lake regulation is outside of the purview of the present Board. It is enough to say that there are a number of difficulties to be met in effecting such regulation, and the construction of works for the purpose cannot be regarded as probable in the near future.

171. Regulation of Lake Ontario Alone. The regulation of lake Ontario alone, in connection with the improvement of the St. Lawrence for navigation and power, forms the subject of a separate study, at the end of this appendix.

COMPENSATING WORKS

172. Compensating Works on Niagara River. It has been shown (paragraph 59) that the present diversions from lake Erie have lowered its level by 0.6 foot, and that it may be lowered by a total of 0.7 foot after the new Welland Ship Canal is in operation. The compensating works herein proposed are designed to raise the low-water levels by 0.7 foot and the high levels a slightly less amount. The plans for the compensating works are designed to meet the winter ice conditions, and to fit in with works for regulating the outflow, should the latter be undertaken at some future time.

173. During the winter an ice sheet forms over the eastern end of lake Erie, up to the shoal water at the head of the Niagara river, but from these shoals to the Falls the river runs open. Winter storms telescope the ice sheet against the shores and shoals, building it up into thick masses, and occasionally

large areas of lake ice are broken up and driven into the river. The volume of ice set in motion at such times may be judged from the fact that in December, 1924, when the run of ice created by one storm jammed at the outlet of the Niagara into lake Ontario, it filled in two days the lower portion of the river to a depth of twenty feet or more for a distance of 7 miles, and backed up the water level at the upper end of the reach some 20 feet above the summer level. If a jam should form in the portion of the river above the falls during a heavy run of ice, it would cut off the water supply to existing power installations, and might so curtail the outflow from lake Erie as to cause a rise in lake levels that cause widespread flood damage. The Board regards it as essential that any compensating works now constructed in the Niagara river, and any regulating works that may be undertaken in the future, be so located and designed that the danger of an ice jam in the upper river will not be incurred.

174. Some of the plans heretofore proposed for compensating and regulating works in the Niagara River have placed these works just above the rapids at the head of the Falls. Since the level of the river at this point must be raised from 4 to 5 feet to produce the desired rise of 0.7 foot in the levels of lake Erie, the attempt to control the levels of lake Erie by works at this site would necessarily result in the slackening of the current through the pool by about 25 per cent and consequently increase the risk of an ice sheet catching across the river, with the consequent formation of an ice jam. The future development of such works into regulating works would entail a still greater slacking of the current, and further increase the hazard. Aside from the question of flowage of the low land bordering the Grass Island Pool, the works at its foot for the control of lake Erie are not regarded as advisable.

175. The construction of submerged rock sills in the narrow and swift portion of the river between Fort Erie and Squaw Island, as proposed in the Warren Report, would accomplish the desired compensation without interfering with the free passage of ice. Such works would, however, greatly increase the cost of a controlled enlargement of the discharge capacity of the river, should the installation of regulating works ever become advisable.

176. Works in Niagara River Proposed by Present Board. The site selected for the compensating works now proposed is therefore just above the contracted section at the head of the river. The construction proposed is shown on the drawing accompanying the main report. It consists of a longitudinal dike, 2,400 feet long, with a riprap weir 1,670 feet long connecting the upper end to the Canadian shore. The crest of this weir is to be but slightly below the river surface at low stages, thus securing at such stages an effective contraction by the longitudinal dike; but at high stages a considerable flow will pass over the weir, reducing the effectiveness of the contraction. The high levels of the lake will be raised by an amount somewhat less than the low levels. Four submerged rock sills are to be placed across the relatively deep hole in the main river channel opposite the dike, with crests at the ruling depth of this part of the river, which is 13 feet below the Lake Survey standard low-water datum. These sills are to have a stop width of 15 feet and side slope of 3 horizontal to 1 vertical. The works proposed will not interfere with the light-draught navigation which occasionally passes through this section. Ordinary commercial navigation will not be affected, since it passes through the Black Rock canal. There is no risk of loss of effectiveness from the scouring of the contracted channel, since the river bed at the site is generally ledge rock. The structures will not interfere with the free passage of ice, nor produce any slacking of the current in the main river channel which would tend to cause ice jams.

177. Estimated Cost of Proposed Works. The estimated cost of the proposed works is as follows:—

Longitudinal dike:	
Cribwork, 22,360 cu. yds. at $8.00	$178,880
Concrete cap, 5,450 cu. yds. at $12.00	65,400
Weir: Rock fill (up to 10-ton stone), 36,000 cu. yds. at $6.50	234,000
Submerged sills (up to 10-ton stone), 17,450 cu. yds. at $6.50	113,425
	$591,705
Engineering and contingencies, approximately 20 per cent	108,295
Total	$700,000

178. Effect on Oscillations at Buffalo. At various times in the past, objection has been made to the construction of compensating or regulation works in the upper part of the Niagara under the theory that this portion of the river now acts as a safety valve to check an extreme rise of lake Erie at Buffalo when westerly storms pile up the water at the eastern end of the lake. Computations show that the relief afforded by the increasing discharge of the Niagara river at such times must be quite small, and since the discharge will increase a little more rapidly with the compensating works than at present, these works will raise the extreme storm levels by an amount a trifle less than that by which they raise the normal levels. The storm levels will therefore be no higher than they would have been had no diversions been made from lakes Michigan and Erie. Even if the compensating works are eventually developed into regulating works, with a free passage substantially as wide as the present restricted section of the river, the effect on increasing the storm fluctuations of level at Buffalo would be negligible, if the gates were not opened to meet the storm rise; but by opening the gates, the present situation might be somewhat improved.

179. Adaptability to Changing Conditions. The degree of compensation afforded by the works herein proposed can be controlled, within limits, by the elevation of the crest of the weir. The computed crest elevation required to provide the desired rise of 0.70 foot in the levels of lake Erie is approximately elevation 570, but discharge determinations made as the work proceeds will permit adjustment of the elevation of the last portion built.

180. Should the diversions affecting lake Erie be reduced in the future to an extent such that these works would raise unduly the high lake levels, a reduction in the amount of compensation afforded can be secured by removing a portion of the weir. Should the construction of regulating works become desirable, sluice gates can be substituted for the weir to form a part of the control structure.

181. Construction Period. The construction of any control works entails a reduction in the outflow from the lake while it is filling. If the construction is spread over two years, the reduction in outflow should not exceed 3,000 to 4,000 cfs. at any time; and such a reduction, if not made at the culmination of a low-water period, will have no noticeable effect on the flow and levels of the Niagara and the St. Lawrence.

182. Compensating Works in the St. Clair River. As previously shown (paragraph 59), the present diversions and changes in the outlet capacity of the St. Clair river have lowered the levels of lakes Michigan and Huron by approximately 1.15 feet, and future extensions of the diversions may slightly increase this figure. The lowering has been in progress for many years, and

has been in part discounted in constructions on the shores of the lake. The Board regards it as safe, however, to raise the levels of lakes Michigan and Huron by one foot.

183. The compensating works proposed in lake Erie will raise the water levels of lake St. Clair by nearly 0.4 foot, and, with the present river channels, would raise the levels of lakes Michigan and Huron by a little less than 0.2 foot. The compensating works proposed in the St. Clair river will, however, reduce this backwater effect on lakes Michigan-Huron to about 0.15 foot. In order to raise the levels of these lakes by one foot, it is necessary, therefore, to increase the fall of the St. Clair river by 0.85 foot.

184. Works Proposed on St. Clair River. Compensating works in the St. Clair river must be designed with full regard to the great volume of commerce that passes through the waterway. To this end, and to permit of the future deepening of the navigation channels to the maximum extent now foreseen, the works recommended are a series of submerged rock sills, at the general locations shown on plate 20, with crests 30 feet below the low-water stage of the river. Eight of these sills are placed in the deep section of the river just below the gorge at its head, and are intended to compensate for the enlargement caused by gravel dredging in that locality, and to stabilize conditions in this controlling section of the river. A total of 23 more sills are distributed along the river from Port Huron-Sarnia to Marine City, at localities where the depth is in excess of 30 feet. The estimated quantity of rock required for the entire construction is 1,156,000 cubic yards. Since suitable rock for their construction is produced on a large scale for fluxing purposes, and is an article of the commerce of the waterway, it can be secured and placed at moderate prices. The estimated cost of the works is $2,700,000.

185. It is recognized that the number of sills required to produce the desired results cannot be foretold with assurance, for data on the effect of such deeply submerged weirs is meager. A study of all available data, including the actual effect of the wrecks of the two schooners sunk near the head of the river in 1900, indicates that the desired results possible may be secured with a fewer number of sills. It is not considered that conclusive data can be secured by experiments with small-scale models, or by further observations on dams in other streams when deeply submerged by floods, for existing data indicates that the effect of such weirs depends on the local conditions of flow. The construction of the sills should be prosecuted consecutively, their effectiveness determined by discharge observations as the work proceeds, such changes made in the location of the sills subsequently constructed as is dictated by the results of these observations, and the work stopped when the desired results are secured.

186. Construction Period. The filling of lakes Michigan and Huron by one foot will require a reduction in the outflow from these lakes by an amount averaging 8,000 cfs. for a period of five years. Since the full effect of the last weirs constructed will not be realized for some years after their completion, no violent reduction in outflow will occur if the work is spread over four years time. To avoid accentuating the effect on existing diversions on the lakes below and on the St. Lawrence, the construction of the compensating works should be suspended during extreme low-water periods.

187. Alternative Plans. The compensating works herein proposed run contrary to the controlled enlargement of the river that will be required should the regulation of its outflow be undertaken at some future time. For this reason the Board has given full consideration to a plan for effecting a part of the com-

pensation by closing one of the channels at Stag island by a dike that could be removed at relatively small cost if regulation works were undertaken. There is, however, a strong likelihood that the concentration of the flow in one channel at Stag island would result in the enlargement of that channel by scour, with consequent loss of effectiveness of the contraction originally secured; and the extent and cost of works required to prevent such enlargement can not be predicted with certainty. At the present time, north-bound traffic follows one of the channels at Stag island and south-bound traffic the other, eliminating any risk of collision at the particular locality. While it is true that the use of a single channel by both up and down commerce is not hazardous in any ordinary sense of the term, yet the volume of traffic is so great that the unnecessary introduction of any additional risk whatever is inadmissable. The desired amount of compensation of levels can be secured at substantially the same probable cost without discontinuing the present local separation of traffic, and it is clearly inadvisable to subject important present commerce to disadvantageous conditions on the slight chance that some money may be saved in the future by such a course.

188. Effect of Ice Gorging. The ice conditions on the St. Clair river are the opposite to those in the upper Niagara river. As has been pointed out, the upper Niagara river always runs open, so that no ice gorging occurs. It is essential that compensating or regulating works preserve this condition, in order that the serious consequences of an ice jam may be prevented. The St. Clair river always closes in winter, with a consequent throttling of the winter flow. The effect of the diminished outflow is a part of the normal regimen of the lakes, to which all interests have adjusted themselves. Since, after an ice cover has once formed, any increase in current velocities tends to aggravate the ice accumulations, it is to be anticipated that the compensating works, which will cause local increases in current velocities, may increase the retardation of the discharge in winter. This effect will tend to increase the effectiveness of the works, and if found at all marked, can be allowed for by omitting some of the sills included in the estimate.

189. Compensation for Enlarged Navigation Channels. The deepening of the navigation channels in the St. Clair and Detroit rivers will tend to increase their outlet capacities and consequently to draw down the levels of lakes Michigan and Huron. To counteract this effect it will be necessary to supplement the compensating works heretofore proposed, in a degree depending upon the dimensions of the channel provided for navigation. The situation does not arise on any other of the lakes, for at no other outlet does an open deep-draft navigation channel pass through the portion of the outlet that controls the level of the lake.

190. The enlargement of the discharge capacity of the St. Clair river consequent to any channel enlargement that now can be foreseen is much less than is commonly supposed. The contracted section at the head of the river, which has a major influence on the discharge capacity, affords a navigable channel exceeding 40 feet in depth. The remainder of the river has navigable depths generally exceeding 30 feet, so that dredging will be required at isolated shoal reaches only. The excavated material can be disposed of most economically by placing it in the portions of the river that are larger than need be, so that a considerable amount of compensation will be effected automatically. The slopes of the river are generally so slight, and the enlargements required for navigation at the various shoal sections are so small in proportion to the present section of

the river, that a convincing determination of the amount by which these slopes would be reduced on account of the dredging is scarcely attainable. A study shows, however, that an entirely uncompensated enlargement of the river to afford a navigable channel 30 feet deep with ample width for navigation could not lower the levels of lakes Michigan-Huron by more than 0.2 foot, and a channel 25 feet deep by more than 0.1 foot. After considering the compensation that can be effected by the dredged material itself, it is considered that the addition of 4 additional sills at a cost of $400,000 will fully compensate for the enlargement of the St. Clair river required to produce a navigation channel 30 feet deep; a total of 3 additional sills at a cost of $300,000 for that caused by a channel 27 feet deep; and 2 additional sills at a cost of $200,000 for a channel 25 feet deep. The cost of compensating work becomes relatively more expensive as the amount of compensation of level increases. If the only compensation undertaken were for the increase in the present outlet capacity due to an enlargement for navigation, the cost would be but about a quarter of the above figure.

191. On the Detroit river, it will be practicable to so place the material excavated in the enlargement of the channel for navigation as to prevent any sensible increase in the discharge capacity of the river, and any consequent effect on lake levels. This course was pursued in the excavation of the Livingstone Channel, which is the most recent and the major enlargement of the river for navigation, and subsequent discharge measurements indicate that the desired result was accomplished. Most of the material to be excavated in this river is rock, so that the spoil will be suitable for the construction of contraction works, and there are sufficient sites at which such contractions can be made without creating conditions detrimental to navigation. The cost of so placing the excavated material is included in the costs of the channels hereinafter presented.

EFFECT OF CONTROL OF LAKE LEVELS ON COST OF INTERLAKE CHANNELS

192. The cost of improving the main navigation channels between and through the lakes, so as to provide the depths required in conjunction with the improvement of the St. Lawrence, obviously depends upon the levels at which the lakes are held. It is not possible to raise the lake levels sufficiently to eliminate channel dredging for this purpose; all that can be accomplished is to reduce the amount of excavation required. Furthermore, the cost of channel dredging will not be reduced in full proportion to the reduction of the yardage of material excavated, as the unit costs of dredging increase as the depth of cut decreases beyond a certain point.

193. The lake levels determined upon as datum planes for navigation channels with various systems of control are shown in the tabulation below. Those for channels secured by excavation only are the levels which would have been available during the navigation season for at least 99 per cent of the time during the past 66 years, had the present diversions and the prospective diversion through the Welland canal been running continuously during that period, and had the outlets to the lakes been in their present condition. In other words they are the monthly mean levels which past experience shows will be exceeded except during one month in a hundred and through the entire navigation seasons of eleven years out of twelve. They are based on the construction of the such relatively minor compensating works in the St. Clair river as

are necessary to preserve the present levels of lakes Michigan and Huron when that river is enlarged for navigation. The datum levels with the proposed compensating works are obtained by adding the amounts by which these works will raise the low levels of the lakes (paragraph 172 and 182). The datum levels with regulating works are obtained by again adding the reduction in the range of stage anticipated from the operation of such works (paragraph 125 and 159), it being assumed that the regulating works would be operated for the benefit of navigation under the program described and to keep the high levels of the lakes from exceeding the levels reached by the compensating works.

DATUM PLANES

—	Superior	Michigan and Huron	St. Clair	Erie
PROPOSED PLANES—				
Without control works	601·0	578·0	573·4	570·25
With compensating works	601·0	579·0	573·75	571·0
With complete regulation	601·4	580·1	574·00	571·5
With modified regulation	601·0	579·4	573·8	571·1
PRESENT PLANES—				
United States datum for channel and harbour improvements	601·6	579·6	573·8	570·8
Canadian datum for channel and harbour improvements	601·0	580·0	....	570·8
For new Welland Ship Canal	....	....	....	568·0

It will be noted that the proposed datum planes for channels without control works are generally lower than the datum planes now adopted by the two countries. The latter were fixed prior to the recent low-water period.

194. The cost of securing channels of 25, 27, and 30 feet depths, respectively, from deep water in lake Superior to deep water in lake Erie, at the lake levels indicated in the preceding paragraph, are shown in the following tabulations. These costs are based on the deepening of existing channels, with such enlargements and rectification as experience with these channels has proved necessary. The estimates for channels 27 and 30 feet deep include the cost of a new lock in the St. Marys river, with chamber 80 feet in width and 1,350 feet in length, and with 30 feet depth over the sills at the datum plane indicated. The Davis and Fourth locks, already built, will pass vessels of 23-foot draft, for which the channels 25 feet in depth are designed.

COST OF CHANNELS FROM LAKE ERIE TO LAKE SUPERIOR

—	Cost of excavation and lock	Cost of control works	Total cost
TWENTY-FIVE FEET DEEP—			
1. Without control works	$45,900,000	$ 50,000	$ 45,950,000
2. With compensating works	41,100,000	3,600,000	44,700,000
3. With partial regulation	39,800,000	14,900,000	54,700,000
4. With complete regulation	36,800,000	36,400,000	73,200,000
TWENTY-SEVEN FEET DEEP—			
1. Without control works	66,500,000	100,000	66,600,000
2. With compensating works	61,400,000	3,700,000	65,100,000
3. With partial regulations	60,000,000	14,900,000	74,900,000
4. With complete regulations	56,900,000	36,400,000	93,300,000
THIRTY FEET DEEP—			
1. Without control works	88,100,000	100,000	88,200,000
2. With compensating works	82,400,000	3,800,000	86,200,000
3. With partial regulation	80,900,000	14,900,000	95,800,000
4. With complete regulation	77,400,000	36,400,000	113,800,000

195. It will be seen that the cost of compensating works will be more than counterbalanced by the saving they effect in providing the main interlake channels. Their construction will effect also a saving in the cost of such enlargement of the harbours on the lakes as is undertaken in conjunction with the provision of deeper main channels. The amount of such enlargement that will be regarded as justifiable can only be roughly forecast, but general figures indicate that the raising of the lake levels by compensating works may save $5,000,000 in the cost of harbour works likely to be undertaken by the two countries.

REGULATION OF LAKE ONTARIO ONLY

196. Necessity for Program of Regulation. All plans for the improvement of the International Rapids Section for the benefit of deep draft navigation and power include a major enlargement of the present control section at the Galop rapids, and the control of the outflow through the wheels of the power plants and the sluice gates of the dams. A program for the regulation of the outflow is therefore requisite.

197. A number of studies have been made by several engineers on the regulation of lake Ontario in connection with the development of power on the St. Lawrence and these studies have been considered by the Board. An examination of the duration curves of outflow through the application of the several programs to past supplies to lake Ontario shows that the benefit to power operation obtained by any of them is not great. The minimum flow is increased only by decreasing the outflow available for a major proportion of the time.

198. Ends Secured by Proposed Program. The program herein presented by the Board is drawn up to secure the following results:—

(*a*) To keep the fluctuations of the levels of lake Ontario within the levels that it has had in the past.

(*b*) To maintain, without impairment, the low water levels of Montreal harbour.

(*c*) To maintain low flows during the winter period December 15 to March 31, in order that the difficulties of winter power operation may not be aggravated.

(*d*) To maintain flows during the first half of April no greater than would naturally occur, in order to avoid the danger of aggravating the spring rise during the breakup of the ice below Montreal.

(*e*) To avoid any material increase in the amount and duration of the high discharges during May, in order not to aggravate high water heights in lake St. Louis during the Ottawa floods.

(*f*) To hold back the natural excess outflow during the early summer months, in order to raise the ordinary levels of lake Ontario.

(*g*) To secure the maximum dependable flow throughout the year for power operation.

199. Specific Program Proposed. The rule curves on which the program is based are shown on plate 21. The regulated outflow for any monthly or half monthly period is to be determined by applying to the rule curve for the month, the level of lake Ontario at the beginning of the period, as established by several gages, the discharge so found to be modified by a correction based on the mean level of lake Huron during the previous month. The controlling sluice gates are then to be so set as to maintain during the period the required discharge out of the lake, through the turbines and sluices.

200. Lake Huron Correction. The correction based on lake Huron levels is for the purpose of applying the forecast that these levels furnish on the supply to lake Ontario. The base levels of lake Huron are as taken as follows:—

	1860 to 1888	After 1889		1860 to 1888	After 1889
April	581.46	580.66	August	582.13	581.33
May	581.78	580.98	September	581.95	580.15
June	582.04	581.24	October	581.73	580.93
July	582.18	581.38	November	581.52	580.72

When the monthly mean level of lake Huron is above its base level for the month the regulated discharge from lake Ontario for the following month, as determined from the rule curves, is increased at the rate of 10,000 cfs. per foot of excess of lake Huron level; when the monthly mean level of lake Huron is below its base level, the regulated discharge from lake Ontario is decreased at the same rate. The correction is not applied, however, to increase the discharge during the first half of April, nor to increase the discharge during any month above 310,000 cfs. No lake Huron correction is made in the winter months, December to March inclusive, since such correction might unduly increase the flow during these months.

201. Thus, in June 1876, the mean level of lake Huron was 583.22 or 1.18 feet above the base for that month. The lake Huron correction for July, 1876 would have been 12,000 cfs. The regulated stage of lake Ontario at the end of June would have been 248.22. The discharge for July, from the diagram, would be 307,000 cfs. The correction would bring the regulated discharge to 319,000 cfs. The regulated discharge is therefore taken at the maximum of 310,000 cfs. The computations of the effect of the program of regulation are illustrated in detail in table 18, which shows the derivation of the regulated levels and outflows for the years 1860 to 1862, inclusive.

TABLE No. 18.—TYPICAL COMPUTATION, PROPOSED REGULATION OF LAKE ONTARIO ONLY

Year	Month	Supply to Ontario (a)	Discharge (b)	L. Huron correction (b)	Corrected discharge (b)	Storage for month (a)	Storage (ft.)	Level at end month
1860	June	....	....	....	....	....	....	247·28
	July	264	268	+11	279	−15	−0·19	7·09
	Aug.	236	258	+11	269	−33	−0·41	6·68
	Sept.	245	251	+11	262	−17	−0·21	6·47
	Oct.	254	247	+10	257	− 3	−0·04	6·43
	Nov.	267	263	+ 9	272	− 5	−0·06	6·37
	Dec.	248	300	....	300	−26	−0·32	6·05
			216	....	216	+16	+0·20	6·25
1861	Jan.	229	210	....	210	+19	+0·24	6·49
	Feb.	257	223	....	223	+34	+0·42	6·91
	Mar.	270	242	....	242	+28	+0·35	7·26
	April	323	268	....	268	+28	+0·35	7·61
			293	+ 9	302	+10	+0·12	7·73
	May	350	291	+ 9	300	+50	+0·62	8·35
	June	307	310	+12	310	− 3	−0·04	8·31
	July	282	310	+13	310	−28	−0·35	7·96
	Aug.	265	288	+13	301	−36	−0·45	7·51
	Sept.	273	289	+14	303	−30	−0·38	7·13
	Oct.	295	288	+15	303	− 8	−0·10	7·03
	Nov.	276	304	+15	310	−34	−0·42	6·61
	Dec.	259	310	....	310	−26	−0·32	6·29
	....	....	218	....	218	+20	+0·25	6·54
1862	Jan.	214	212	....	212	+ 2	+0·02	6·54
	Feb.	242	224	....	224	18	+0·22	6·78
	Mar.	293	240	....	240	+53	+0·66	7·44
	April	355	272	....	272	+42	+0·52	7·96
			310	+11	310	+22	+0·28	8·24
	May	331	310	+11	310	+21	+0·26	8·50
	June	297	310	+11	310	−13	−0·16	8·34
	July	287	310	+10	310	−23	−0·29	8·05
	Aug.	249	292	+ 9	301	−52	−0·65	7·40
	Sept.	233	283	+ 9	292	−59	−0·74	6·66
	Oct.	235	256	+ 9	265	−30	−0·38	6·28
	Nov.	244	247	+14	261	−17	−0·21	6·07
	Dec.	257	239	....	239	+ 9	−0·11	6·18
			217	....	217	+20	+0·25	6·43

(a) In thousands of cubic feet per second. *(b)* In thousands of cubic feet per second per month.

202. RESULTS SECURED. The program was tested by applying it to the conditions that would have obtained from 1860 to 1925 had a diversion of 8,500 cfs. from the lake basin been continuous during the period. The resulting levels and outflows, month by month, together with the natural levels and outflows, are shown in table 19. The duration curves of outflows, and of lake levels are shown on plates 10, 11, and 22.

203. An examination of the results from the proposed program shows:—

—	Without regulation: With actual diversions	Without regulation: With continuous diversion of 8,500 cfs.	Regulated
Maximum level Lake Ontario at end of any month	248·79 (May, 1870)	248·37 (May, 1870)	248·95 (May, 1870)
Minimum level, Lake Ontario, at end of any month	243·42 (Nov., 1895)	243·00 (Nov., 1895)	243·58 (Nov., 1895)
Level of Lake Ontario exceeded 90 per cent of time during navigation seasons	245·0	....	245·6
Number of months in 65 years in which stage of Lake Ontario exceeded 248·1 (at end of month)	26	8	20
Maximum monthly mean outflow	318,000 cfs.	310,000 cfs.	310,000 cfs.
Minimum monthly mean outflow	174,000 cfs.	166,000 cfs.	182,000 cfs.
Outflow exceeded—			
90 per cent of time	....	199,000	203,000
70 per cent of time	....	223,000	212,000
50 per cent of time	....	238,000	233,000

204. The program would maintain the flow during the summer and fall months sufficiently to preserve completely the low water levels of Montreal harbour resulting from the unregulated flow. The regulated flows during the first half of April would not exceed, in amount or frequency, the unregulated outflow. The maximum regulated flow for May would not exceed that which has occurred in nature.

205. The regulation of lake Ontario, in such manner as to injure no interest, and at the same time to effect some improvement of lake levels and outflow, is therefore wholly practicable.

206. ACKNOWLEDGMENTS. The program for the complete regulation of the lakes, described in this report, was conceived and worked up by Mr. E. W. Lane, temporarily employed as Assistant Engineer, and placed in charge of the investigations relative to regulation. The program for the regulation with partial control of the St. Clair river, and the studies looking to raising the levels of lake Ontario, were conceived and worked up by Mr. F. G. Ray, Senior Engineer, U.S. Lake Survey, assisted by Mr. Sherman Moore, Associate Engineer. Mr. Ray's intimate knowledge of the behavior of the Great Lakes, gained by his long service in the United States Lake Survey, was drawn on throughout.

207. The program for the regulation of lake Ontario was formulated by Mr. D. W. McLachlan, Chairman of the Canadian Section of the Board. Minor modifications of the program were worked out by Lt.-Col. G. B. Pillsbury, that it might rigidly meet all of the requirements set forth in the preceding paragraphs.

TABLE 1—LOCAL SUPPLY TO LAKE SUPERIOR

In Thousand Second Feet

—	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
1860	16	40	129	180	168	129	108	112	109	85	13	1	90·8
1861	12	9	123	266	235	162	133	91	99	58	−22	−30	94·7
1862	−7	48	93	207	210	92	122	151	113	36	− 9	11	88·9
1863	29	23	53	105	90	90	211	205	72	7	6	15	75·5
1864	−10	44	85	101	129	122	101	111	68	5	17	16	65·8
1865	34	40	114	232	236	222	171	122	71	−23	−57	−20	95·2
1866	−11	28	142	198	159	174	185	97	53	45	51	63	98·7
1867	19	24	80	97	200	262	141	97	115	29	−36	5	86·1
1868	−45	25	166	180	142	112	118	102	113	116	51	−22	88·2
1869	4	−53	86	246	158	156	238	328	186	−27	−62	−58	100·2
1870	9	13	99	157	116	89	126	123	99	37	−102	−103	57·8
1871	−41	7	217	246	189	123	112	119	99	66	−56	−83	85·7
1872	16	26	25	156	253	198	168	157	114	58	19	20	100·8
1873	7	18	84	159	212	192	178	145	101	65	24	−33	96·0
1874	3	69	85	102	127	192	179	133	129	84	15	− 8	92·5
1875	26	81	86	124	189	160	115	155	123	57	40	19	97·9
1876	17	31	68	178	299	294	203	121	46	32	32	−10	109·3
1877	−10	− 2	31	69	117	193	171	84	67	61	42	55	73·2
1878	81	−45	60	114	171	146	79	38	63	61	− 9	37	56·3
1879	76	107	37	−75	42	148	133	76	69	75	− 7	−25	54·7
1880	28	36	42	161	299	247	115	88	85	69	34	− 4	100·0
1881	15	38	43	107	203	172	108	135	191	148	41	−11	99·2
1882	−18	10	42	87	112	166	187	121	71	60	54	14	75·5
1883	−13	18	113	118	91	142	130	92	46	26	37	52	71·0
1884	36	23	14	63	141	133	104	126	190	126	33	6	82·9
1885	7	25	48	115	180	177	151	104	50	33	3	−10	73·6
1886	16	32	71	125	142	118	81	69	99	76	34	− 1	71·8
1887	21	127	145	55	62	157	149	76	47	35	3	17	74·5
1888	51	51	50	143	283	263	154	114	73	59	8	−34	101·3
1889	−18	− 5	40	129	156	135	150	140	82	5	−27	− 2	65·4
1890	25	− 8	14	90	177	209	161	131	100	42	−19	−47	72·9
1891	−23	30	45	89	112	113	101	61	79	66	−15	1	54·9
1892	15	−18	31	113	183	143	99	103	68	29	− 9	−31	60·5
1893	− 9	41	74	157	234	216	138	75	56	44	8	− 4	85·8
1894	1	42	97	225	249	136	121	98	78	83	45	− 1	97·8
1895	−12	1	24	115	191	173	129	120	124	54	−23	− 8	74·0
1896	4	0	48	97	251	163	103	66	4	39	69	28	72·7
1897	10	12	61	135	190	194	161	103	45	4	−40	−59	68·0
1898	−26	− 6	27	103	188	230	172	122	92	40	7	−21	77·3
1899	−26	35	66	182	282	213	159	149	95	45	37	− 8	102·4
1900	−13	2	19	84	114	126	179	232	197	103	25	−36	86·0
Average—1860-1900	7·2	26·3	69·7	135·0	177·6	167·9	142·5	119·3	92·2	51·5	6·2	− 7·5	82·3
1901	−29	−17	24	109	141	179	188	81	62	71	11	−41	64·9
1902	−28	− 2	42	125	169	163	116	84	63	55	36	−25	66·5
1903	−35	− 4	74	179	215	178	131	103	106	66	−23	−39	79·3
1904	− 6	22	41	112	176	150	115	123	141	108	− 2	−38	78·5
1905	−24	− 7	87	152	149	165	159	145	129	68	25	9	88·1
1906	− 6	−15	27	121	186	15	113	96	73	38	17	6	67·9
1907	9	19	46	99	174	183	148	167	131	40	−19	−48	79·1
1908	−35	2	25	115	225	221	146	75	29	− 8	−23	−15	63·1
1909	−22	− 2	25	100	167	164	150	118	63	57	68	38	77·2
1910	−16	−26	42	102	108	91	84	86	65	26	−19	−40	41·9
1911	−31	−24	− 9	78	175	194	195	155	77	37	13	12	72·7
1912	− 6	− 5	40	135	184	140	118	117	60	34	− 1	−26	67·5
1913	−43	− 9	70	158	187	167	140	105	133	69	21	− 7	82·6
1914	−11	−21	4	117	172	150	121	97	75	29	−23	−35	56·3
1915	− 1	2	5	88	170	182	151	103	140	143	70	38	90·9
1916	24	−11	58	214	264	210	143	140	108	60	28	− 7	102·6
1917	−28	11	63	98	145	138	102	88	72	33	−13	−29	56·7
1918	−15	− 1	18	81	166	155	111	108	79	72	51	10	69·6
1919	− 2	−17	43	115	126	112	77	45	35	45	28	−15	49·3
1920	−13	27	113	138	155	170	117	78	33	1	−17	−12	65·8
1921	−29	−44	40	151	170	127	110	72	20	−23	−45	−52	41·4
1922	−51	−13	48	153	168	135	115	79	21	−12	−24	−34	48·8
1923	−32	−27	16	85	102	105	117	78	54	38	− 1	−29	42·2
1924	−25	−37	− 1	74	96	83	108	133	91	26	−16	−53	39·9
1925	−35	− 8	32	79	117	131	97	59	43	17	−25	−49	38·2
Average—1901-1925	−19·6	− 8·3	38·9	119·1	164·3	154·1	126·9	101·4	76·9	43·6	4·7	−19·2	65·2
1860-1925	− 2·9	13·2	58·0	129·0	172·6	162·6	136·6	112·5	86·4	48·5	5·6	−12·0	75·9

TABLE 2—TOTAL SUPPLY TO LAKE MICHIGAN-HURON

In Thousand Second Feet—8,500 Second Feet Deducted for Chicago Diversion

—	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
1860	202	196	225	255	262	262	200	136	102	59	96	135	177·5
1861	197	301	324	331	347	293	307	209	119	140	120	122	234·2
1862	121	198	321	297	302	221	189	195	166	103	79	153	195·4
1863	202	211	189	251	269	218	162	129	132	82	171	228	187·0
1864	112	231	192	236	317	163	128	86	23	53	110	87	144·8
1865	130	219	334	350	235	300	307	175	110	7	−30	46	181·9
1866	52	129	287	331	290	313	260	164	128	135	95	106	190·8
1867	195	242	278	314	311	310	218	112	50	5	−15	57	173·2
1868	128	326	324	226	301	243	111	45	67	102	96	83	171·0
1869	167	117	184	347	376	408	340	235	79	77	93	131	212·8
1870	204	276	349	380	313	263	213	211	145	16	15	137	210·2
1871	212	303	390	336	305	232	164	− 7	−138	13	26	− 1	152·9
1872	141	119	182	291	330	279	187	166	136	86	−53	8	156·0
1873	179	257	378	452	467	350	214	180	142	137	130	174	255·0
1874	212	244	203	167	272	284	185	148	134	43	79	115	173·8
1875	123	189	272	366	375	294	242	222	162	133	109	142	219·1
1876	237	276	298	405	440	423	304	197	94	108	136	80	249·8
1877	154	178	188	233	183	242	210	138	137	178	174	169	182·0
1878	146	168	219	279	325	255	164	107	134	157	111	48	176·1
1879	79	119	186	223	243	231	167	130	114	95	151	196	161·2
1880	179	162	206	292	396	383	255	142	71	60	99	126	197·6
1881	233	309	215	289	347	264	200	137	221	278	177	128	233·2
1882	130	223	294	277	288	298	265	205	103	83	88	88	195·2
1883	140	216	222	363	427	436	362	186	88	110	162	142	237·8
1884	110	201	301	325	292	236	175	114	162	162	94	206	198·2
1885	254	226	236	338	366	301	288	244	155	122	104	182	234·7
1886	213	226	317	342	311	216	145	136	144	126	71	101	195·7
1887	247	333	220	236	283	247	184	95	47	41	56	117	175·5
1888	140	217	270	336	359	286	206	151	87	114	75	80	193·4
1889	161	147	159	193	302	347	213	126	80	39	60	159	165·5
1890	181	145	224	298	340	324	216	135	97	91	40	75	180·5
1891	107	151	249	299	225	185	157	119	46	12	77	173	150·0
1892	200	152	163	256	347	333	237	164	88	57	52	78	177·3
1893	128	185	294	390	364	289	180	86	70	75	71	146	189·8
1894	182	224	269	341	348	279	186	86	67	85	62	47	181·3
1895	85	131	207	242	227	181	140	110	48	31	51	139	132·7
1896	202	144	165	267	328	259	172	141	107	100	111	156	179·3
1897	172	214	278	362	359	296	229	127	47	63	70	100	193·1
1898	173	247	330	318	255	236	162	84	86	88	56	76	175·9
1899	127	205	199	331	381	338	235	135	62	66	59	55	182·8
1900	103	161	177	248	256	262	260	225	187	168	115	61	185·3
Average— 1860-1900	162·4	207·8	251·7	302·8	318·6	282·4	213·1	144·5	100·0	90·3	84·0	113·4	189·2
1901	81	134	248	283	269	248	238	165	78	58	51	45	158·3
1902	37	98	219	279	320	324	271	119	55	109	90	64	165·4
1903	96	189	273	277	247	272	215	194	189	85	20	67	177·0
1904	116	183	313	386	376	316	203	160	148	102	29	57	199·1
1905	41	101	251	348	359	344	232	177	97	61	75	125	184·3
1906	200	206	226	293	297	247	206	122	73	99	143	152	188·7
1907	138	147	224	290	316	313	206	166	135	55	58	121	180·8
1908	88	137	201	373	364	304	222	82	6	−20	12	73	153·5
1909	113	157	209	366	378	257	188	122	26	34	123	112	173·8
1910	83	143	247	290	263	190	136	140	129	80	37	30	147·3
1911	95	124	182	278	311	234	144	127	118	111	134	149	167·3
1912	83	122	196	333	414	308	220	240	165	129	136	106	204·3
1913	109	139	350	413	285	244	203	120	74	83	93	90	183·6
1914	86	116	151	252	301	278	198	129	108	47	19	57	145·2
1915	108	178	132	173	243	239	257	194	103	72	85	104	157·3
1916	153	179	241	393	439	377	216	97	74	174	205	140	224·0
1917	102	147	280	352	373	397	296	148	75	91	64	58	198·6
1918	131	222	304	277	327	271	172	108	71	103	168	130	190·3
1919	100	159	270	348	299	188	124	78	75	104	72	61	156·5
1920	65	134	284	349	257	265	239	163	89	57	61	98	171·8
1921	125	122	280	344	236	163	101	95	111	81	92	95	153·8
1922	57	158	341	414	330	253	202	125	43	2	−13	49	163·4
1923	56	108	250	328	333	257	162	119	101	46	35	58	154·4
1924	124	147	194	297	293	245	245	181	82	−13	−20	20	149·6
1925	60	153	196	189	177	198	156	87	36	39	60	100	120·9
Average— 1901-1925	97·9	148·1	242·5	317·0	312·3	269·3	202·1	138·3	90·4	71·6	73·2	86·5	170·8
1860-1925	138·0	185·2	248·2	308·2	316·2	277·5	209·0	142·2	96·4	83·2	79·9	103·2	182·3

TABLE 3—LOCAL SUPPLY TO LAKES MICHIGAN-HURON

In Thousand Second Feet—8,500 Second Feet Deducted for Chicago Diversion

—	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
1860	108	108	138	162	160	156	94	28	−4	−48	−6	42	78·2
1861	110	220	246	244	242	184	194	96	10	30	18	30	135·3
1862	38	120	242	218	204	122	90	92	62	0	−16	66	103·2
1863	120	132	114	176	188	138	78	30	34	−12	86	146	102·5
1864	38	162	122	166	240	82	44	2	−64	−28	34	16	67·8
1865	64	154	272	278	148	204	202	68	4	−94	−118	−34	95·7
1866	−20	62	220	254	204	222	162	60	32	38	6	16	104·7
1867	112	162	202	234	228	212	112	8	−54	−98	−108	−28	81·8
1868	48	260	250	148	210	154	16	−48	−28	8	−2	−4	84·3
1869	86	42	120	270	286	318	240	124	−50	−40	−16	38	118·2
1870	118	196	268	298	220	174	118	116	48	−78	−74	70	122·8
1871	138	232	326	268	224	142	74	−100	−232	−76	−58	−76	71·8
1872	72	52	120	230	248	194	92	64	32	−14	−150	−78	71·8
1873	102	184	304	378	380	260	114	74	34	32	30	80	164·3
1874	130	166	128	94	190	192	84	46	32	−62	−20	18	83·2
1875	36	108	192	280	282	194	140	120	54	28	10	56	125·0
1876	152	192	220	326	344	314	184	76	−28	−6	28	−16	148·8
1877	64	88	100	148	98	152	112	38	42	82	84	82	90·8
1878	64	92	146	206	246	170	76	20	54	74	30	−28	95·8
1879	12	62	134	168	180	164	94	56	42	22	82	136	96·0
1880	124	108	154	240	326	296	162	52	−22	−28	10	44	122·2
1881	158	236	142	218	266	178	110	48	128	174	76	34	147·3
1882	48	146	220	204	206	214	172	110	10	−8	−2	4	110·3
1883	66	144	150	290	354	354	276	90	0	26	80	66	158·0
1884	36	132	234	262	220	162	96	34	80	78	8	126	122·3
1885	178	152	166	271	286	213	196	147	64	35	18	103	152·4
1886	142	159	250	275	233	135	60	48	59	40	−13	27	117·9
1887	178	267	155	174	212	166	94	8	−37	−47	−26	44	99·0
1888	71	156	208	274	283	190	107	52	−10	17	−18	2	111·0
1889	89	81	92	126	224	265	126	39	−7	−45	−18	89	88·4
1890	110	85	164	239	272	244	129	50	14	9	−39	2	106·6
1891	48	90	191	237	154	115	85	47	−25	−60	7	110	83·3
1892	138	97	112	202	282	261	162	89	12	−17	−16	15	111·4
1893	76	136	245	336	299	214	102	6	−7	−1	−4	81	123·6
1894	121	165	212	277	265	191	96	−4	−21	−4	−25	−34	103·3
1895	10	58	138	174	151	97	52	22	−44	−63	−33	58	51·7
1896	131	73	98	198	248	171	81	50	18	18	28	76	99·2
1897	97	145	208	291	280	210	138	34	−43	−24	−16	24	112·0
1898	106	185	271	256	186	159	80	0	1	5	−25	−4	101·7
1899	58	138	133	267	299	249	141	39	−38	−29	−33	−34	99·2
1900	24	85	105	176	180	184	178	139	93	73	20	−24	102·8
Average— 1860-1900	87·8	137·4	183·2	232·5	237·8	195·5	121·0	50·5	6·0	−2·3	−4·4	32·7	106·5
1901	1	59	180	213	193	169	151	75	−9	−20	−27	−26	79·9
1902	−30	36	162	218	254	254	197	43	−22	34	15	−6	96·3
1903	31	128	213	215	177	194	135	113	109	4	−61	−7	104·3
1904	44	112	246	315	300	234	118	73	60	11	−59	−25	119·1
1905	−37	30	184	274	279	261	144	89	8	−33	−14	41	102·2
1906	118	129	152	217	215	161	117	34	−15	12	58	73	105·9
1907	64	76	158	219	243	234	121	77	42	−34	−30	39	100·8
1908	13	68	136	311	296	225	134	−7	−80	−102	−68	−2	77·0
1909	46	97	156	312	319	189	115	40	−57	−46	50	33	104·5
1910	12	77	185	230	201	121	64	67	55	7	−32	−32	79·6
1911	40	73	133	228	257	178	85	65	56	49	74	92	110·8
1912	27	68	143	279	355	245	157	173	97	60	67	41	142·7
1913	47	78	292	351	218	175	132	47	−1	5	17	17	114·8
1914	15	48	86	188	232	206	125	54	30	−42	−68	−13	71·8
1915	42	111	66	110	173	167	180	116	27	−3	8	31	85·7
1916	83	110	172	319	356	278	117	−8	−43	55	89	30	129·8
1917	11	59	194	262	281	306	209	72	0	13	−10	−1	116·3
1918	71	164	245	219	268	206	114	47	4	34	104	75	129·3
1919	45	106	217	295	244	135	70	26	20	49	16	5	102·3
1920	8	78	228	294	183	188	158	63	8	−2	3	43	104·3
1921	72	68	228	291	188	117	47	41	55	26	44	50	102·3
1922	15	114	297	370	286	212	159	81	0	−45	−61	1	119·1
1923	8	59	199	277	278	203	109	66	49	−4	−14	8	103·2
1924	74	97	143	245	240	195	198	131	33	−63	−71	−30	99·3
1925	8	102	144	135	122	145	103	30	−26	−27	−3	41	64·5
Average— 1901-1925	33·1	85·9	182·4	255·5	246·3	199·9	130·4	64·3	16·0	−2·5	1·1	19·1	102·6
1860-1925	67·1	117·9	182·9	241·2	241·0	197·2	124·6	55·7	9·8	−2·3	−2·3	27·6	105·0

TABLE 4—TOTAL SUPPLY TO LAKE ERIE

In Thousand Second Feet—8,500 Second Feet Deducted for Chicago Diversion

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
1860	175	211	278	285	250	220	209	200	184	192	197	186	215·6
1861	173	206	287	310	267	229	224	228	209	213	213	208	230·6
1862	203	206	275	301	257	241	222	197	188	179	194	237	225·0
1863	261	242	231	246	237	215	217	200	170	161	173	179	211·0
1864	182	215	239	276	261	208	189	187	178	173	191	178	206·4
1865	135	160	240	273	244	208	204	200	189	164	165	168	195·8
1866	160	196	242	247	233	234	208	191	204	194	190	188	207·3
1867	165	195	238	253	164	230	193	176	161	150	146	158	194·1
1868	145	181	257	271	254	237	188	163	160	155	166	171	195·7
1869	177	203	234	245	259	256	236	199	176	157	190	235	213·9
1870	235	213	233	270	240	227	229	210	188	175	183	185	215·7
1871	170	199	253	254	237	218	207	193	163	147	157	153	195·9
1872	162	154	179	213	232	216	194	178	166	160	148	154	179·7
1873	167	177	248	311	256	221	213	190	168	172	207	245	214·6
1874	237	218	225	230	229	228	215	185	159	151	154	160	199·3
1875	158	175	209	237	247	239	218	202	172	161	197	207	201·8
1876	226	279	290	282	267	245	223	211	195	196	208	174	233·0
1877	175	178	208	244	230	232	224	202	188	179	205	214	206·6
1878	219	227	244	260	244	228	215	201	193	183	201	189	217·0
1879	171	191	220	236	223	217	201	175	168	158	172	230	196·8
1880	230	211	222	234	236	226	212	188	171	170	172	149	201·8
1881	164	210	246	268	252	231	200	176	182	189	202	240	213·3
1882	241	242	261	254	255	242	226	209	187	175	162	165	218·3
1883	202	224	223	241	280	285	247	216	195	185	193	199	224·2
1884	202	240	259	275	257	228	213	196	177	167	170	186	214·2
1885	174	170	226	292	290	261	232	226	217	215	218	223	228·7
1886	186	152	242	290	253	237	220	203	195	182	187	198	212·1
1887	214	285	276	239	245	226	202	192	172	169	193	199	217·7
1888	181	182	234	257	231	230	224	186	164	188	199	202	206·5
1889	198	180	201	229	237	248	210	173	159	155	191	233	201·2
1890	248	234	249	266	266	236	184	184	189	199	199	184	219·8
1891	190	226	222	188	200	202	185	174	162	141	163	193	187·2
1892	174	161	207	266	287	269	211	179	159	152	160	159	198·7
1893	161	194	235	284	269	214	184	164	159	156	178	215	201·1
1894	205	182	213	238	244	224	183	172	169	164	175	166	194·6
1895	155	154	186	199	199	183	173	169	148	143	170	185	172·0
1896	175	165	188	219	222	193	197	188	155	146	160	175	181·9
1897	194	209	235	244	229	212	195	177	152	151	178	188	197·0
1898	201	211	238	244	219	196	181	171	160	172	177	193	196·9
1899	187	192	224	224	221	202	181	157	154	167	164	174	187·3
1900	198	219	226	221	215	197	194	180	163	160	174	180	193·9
Average— 1860-1900	189·7	201·7	235·2	254·0	244·8	226·6	206·9	189·5	174·8	169·9	181·5	190·9	205·5
1901	157	144	185	198	201	221	194	177	164	153	174	176	178·7
1902	152	158	219	236	223	244	243	188	177	182	171	172	197·1
1903	189	223	272	260	214	210	200	187	178	158	150	171	201·0
1904	174	222	284	289	245	233	204	188	179	169	162	165	209·5
1905	166	156	207	261	266	250	217	194	182	170	178	203	204·2
1906	206	178	200	234	228	219	210	190	177	191	216	236	207·1
1907	221	175	216	246	246	245	213	189	196	194	189	218	212·3
1908	212	211	267	271	242	218	205	186	167	148	150	184	205·1
1909	189	207	226	261	277	227	199	177	146	157	170	179	201·3
1910	172	204	239	248	241	199	186	178	177	167	161	165	194·8
1911	170	177	208	229	215	187	179	176	180	165	189	198	189·4
1912	171	176	243	278	230	208	198	206	189	172	173	220	205·3
1913	255	228	296	324	230	214	199	179	165	179	192	196	221·4
1914	177	161	209	280	262	213	190	183	176	150	163	168	194·3
1915	178	198	191	197	211	213	227	213	182	161	164	202	194·8
1916	238	217	222	265	265	247	200	167	158	170	179	192	210·0
1917	187	186	262	289	272	282	244	202	186	207	206	156	223·3
1918	154	216	238	195	220	232	214	204	199	189	205	206	206·0
1919	216	226	255	287	274	222	198	188	184	180	179	154	213·6
1920	126	147	222	269	249	228	222	196	175	177	193	210	201·2
1921	199	209	248	268	231	204	189	172	163	175	191	187	203·0
1922	167	175	247	276	244	218	196	185	168	149	151	173	195·8
1923	168	165	215	234	223	210	180	167	161	152	179	206	188·3
1924	205	179	208	245	233	223	203	178	173	146	141	162	191·3
1925	156	187	221	204	175	173	176	167	149	147	167	133	171·3
Average— 1901-1925	184·2	189·0	232·0	253·8	236·7	221·6	203·4	185·5	174·0	168·3	175·7	185·3	200·8
1860-1925	187·6	196·9	234·0	253·9	241·7	224·7	205·6	188·0	174·5	169·3	179·3	188·7	203·7

TABLE 5—LOCAL SUPPLY TO LAKE ERIE

In Thousand Second Feet

—	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
1860	−31	66	92	94	45	− 2	−23	−28	−43	−17	−16	−13	10·3
1861	−23	31	76	106	57	12	2	2	−12	− 6	− 2	− 2	20·1
1862	3	46	62	97	45	27	10	−16	−27	−36	−15	32	19·0
1863	59	42	38	48	34	9	13	− 1	−30	−42	−22	−23	10·4
1864	−14	17	38	90	66	17	− 4	− 3	− 8	− 9	12	6	17·3
1865	−22	14	57	84	57	21	6	2	− 8	−29	−20	− 9	12·8
1866	−11	25	69	73	56	54	23	4	19	13	8	17	29·2
1867	−19	11	70	66	75	40	− 6	−19	−34	−39	−38	−16	7·6
1868	−29	17	69	91	72	54	2	−17	−18	−21	−13	0	17·3
1869	2	41	75	75	83	72	48	4	−20	−32	1	55	33·7
1870	65	42	55	76	41	25	26	10	−20	−28	−12	2	23·5
1871	−28	34	51	50	26	8	− 5	−15	−30	−34	−26	−13	1·5
1872	−12	−20	5	40	53	34	8	− 5	−18	−19	−31	− 9	2·2
1873	− 3	10	77	137	67	19	13	−12	−32	−29	+ 9	52	25·7
1874	81	91	36	35	37	22	12	−18	−48	−51	−38	−34	10·4
1875	−35	−17	17	48	48	34	10	− 5	−39	−46	−10	15	1·7
1876	26	84	101	86	76	28	− 6	−18	−38	−29	−15	−31	22·0
1877	−30	−10	68	76	56	15	5	−15	−26	−30	− 3	8	9·5
1878	18	72	57	64	38	17	4	− 8	−13	−25	− 7	6	18·6
1879	− 6	41	40	48	37	26	9	−15	−24	−30	−17	45	12·8
1880	46	35	39	54	48	30	9	−13	−31	−26	−24	−32	11·3
1881	−14	17	58	72	52	31	− 6	−25	−19	−21	−15	39	14·1
1882	41	56	66	56	57	37	23	5	−24	−33	−43	−29	17·7
1883	6	25	44	44	71	75	32	− 5	−24	−29	−31	−13	16·3
1884	44	70	52	63	40	13	− 5	−21	−37	−53	−46	−19	8·4
1885	−33	−44	22	86	70	38	5	− 2	−11	−10	− 3	10	10·7
1886	12	− 1	48	90	28	1	−13	−26	−32	−42	−34	−11	1·6
1887	5	73	83	38	37	9	−19	−24	−39	−39	−10	4	9·8
1888	−11	− 9	49	62	38	18	14	−25	−44	−14	− 1	10	7·3
1889	9	13	33	58	53	54	11	−26	−39	−37	4	56	15·8
1890	68	58	77	90	87	49	−10	−12	− 4	10	13	6	36·0
1891	17	50	67	13	22	13	− 5	−14	−24	−38	−11	21	9·3
1892	8	20	59	98	115	92	27	− 8	−25	−31	−22	−12	26·8
1893	14	46	63	109	93	24	−10	−28	−29	−30	− 6	38	23·7
1894	24	16	33	62	57	24	−21	−27	−28	−28	−17	−16	6·6
1895	−15	−11	11	36	28	− 1	−10	−11	−31	−33	0	24	−1·1
1896	12	27	38	60	60	18	21	15	−19	−24	−13	11	17·2
1897	26	49	70	78	54	25	4	−14	−36	−32	− 4	14	19·5
1898	29	64	69	72	45	10	− 8	−16	−27	− 9	− 4	19	20·3
1899	18	24	119	69	37	12	−16	−37	−39	−19	−21	− 1	12·2
1900	66	100	101	51	40	14	5	− 6	−28	−31	−19	− 3	24·1
Average— 1860-1900	8·9	32·1	57·4	69·4	53·7	27·3	4·3	−12·0	−25·8	−27·0	−13·7	5·0	14·9
1901	1	42	59	77	31	23	− 6	−24	−32	−40	−18	23	11·3
1902	41	41	47	63	40	58	57	− 1	− 8	3	−10	1	27·7
1903	68	108	112	84	32	26	12	− 1	−12	−34	−39	16	31·0
1904	39	95	140	112	54	35	2	−14	−21	−31	−36	−18	29·8
1905	73	58	61	70	71	49	13	− 9	−22	−30	−19	13	27·3
1906	26	42	40	48	26	17	6	−11	−21	− 1	26	71	22·4
1907	82	52	52	60	49	45	7	−13	− 7	− 4	− 4	33	29·3
1908	92	100	161	88	46	16	− 2	−17	−32	−43	−37	0	31·0
1909	29	100	82	82	92	35	5	−14	−44	−27	−11	10	28·3
1910	47	71	59	65	53	9	− 2	− 9	− 9	−17	−21	14	21·7
1911	45	55	38	58	36	4	− 4	− 5	3	−10	14	30	22·0
1912	46	49	99	110	47	22	11	18	− 4	−18	−20	29	32·4
1913	80	100	138	146	43	25	1	−20	−30	−11	2	13	40·6
1914	31	25	58	107	82	32	1	− 6	−16	−37	−20	7	22·0
1915	61	65	45	31	40	39	45	30	1	−18	−12	39	30·5
1916	85	94	100	116	81	55	3	−33	−40	−25	−14	7	35·8
1917	42	41	70	104	78	81	32	−10	−21	4	10	6	36·4
1918	28	73	69	64	20	24	1	− 8	−12	−13	4	10	21·7
1919	26	48	73	100	78	24	− 6	−11	−14	−13	−11	0	24·5
1920	18	29	67	81	63	37	22	− 4	−26	−12	11	27	26·1
1921	18	84	86	86	51	19	− 2	−16	−26	− 9	16	18	27·1
1922	39	49	81	100	60	28	− 1	−11	−26	−37	−30	− 8	20·3
1923	27	50	50	68	40	23	− 6	−17	−32	−28	3	37	18·7
1924	57	58	61	84	58	46	24	− 4	−11	−29	−30	15	27·4
1925	28	55	71	44	11	10	11	6	−10	− 9	15	−22	17·5
Average— 1901-1925	45·2	63·4	76·8	81·9	51·3	31·3	9·0	− 8·2	−18·5	−19·6	−9·21	4·8	26·5
1860-1925	22·6	43·9	64·7	74·1	52·8	28·8	6·0	−10·6	−23·1	−24·2	−12·0	8·7	19·3

TABLE 6—TOTAL SUPPLY TO LAKE ONTARIO

In Thousand Second Feet—8,500 Second Feet Deducted for Chicago Diversion

—	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
1861	229	257	270	323	350	307	282	265	273	295	276	259	282·2
1862	214	242	293	355	331	297	287	249	233	235	244	257	269·8
1863	246	239	268	320	312	283	249	243	245	234	249	244	261·0
1864	198	217	259	323	333	292	252	235	244	246	263	284	262·2
1865	260	227	243	285	288	275	244	216	218	223	222	221	243·5
1866	189	193	224	265	250	296	298	254	247	240	244	250	245·8
1867	219	255	301	338	330	295	250	231	217	192	181	182	249·3
1868	193	190	238	287	283	280	240	230	212	206	228	237	235·3
1869	207	202	217	299	303	295	295	275	264	252	254	295	263·2
1870	272	255	282	357	321	279	275	246	234	231	224	238	267·8
1871	213	220	266	302	284	261	242	226	215	205	198	199	235·9
1872	166	151	194	238	243	248	230	220	206	210	204	187	208·1
1873	184	193	275	346	282	262	252	230	217	217	240	272	247·5
1874	266	269	270	265	268	277	263	232	210	208	200	201	244·3
1875	169	164	231	273	259	252	242	228	214	211	209	229	223·4
1876	252	265	293	340	322	307	280	243	234	241	236	227	270·0
1877	185	211	255	283	256	254	248	222	207	208	230	240	233·3
1878	226	249	268	281	280	263	259	250	240	239	279	291	260·4
1879	211	216	235	280	269	268	240	219	209	200	211	232	231·7
1880	234	238	244	262	269	268	239	214	219	212	234	200	235·2
1881	163	212	252	263	260	260	241	208	202	217	226	250	229·5
1882	250	253	275	281	293	297	264	240	223	209	209	215	250·8
1883	194	196	235	291	314	325	298	254	233	233	242	247	255·2
1884	231	267	291	311	286	272	267	253	233	219	221	237	257·3
1885	208	182	216	292	311	293	273	253	249	253	270	288	257·3
1886	265	255	281	323	296	267	251	244	243	230	236	243	261·2
1887	243	300	285	310	308	275	249	223	216	221	212	211	254·4
1888	187	190	235	272	252	254	248	228	211	214	227	239	229·8
1889	231	216	228	263	268	278	260	223	204	196	233	280	240·0
1890	264	258	266	292	315	306	253	230	237	246	252	229	262·3
1891	221	256	279	284	253	232	228	212	193	172	188	215	227·8
1892	197	181	211	248	250	281	270	235	220	205	211	206	226·3
1893	175	189	240	316	322	272	236	222	218	202	208	232	236·0
1894	230	207	235	252	276	273	224	197	201	203	193	194	223·8
1895	181	164	190	242	220	202	189	175	172	158	176	201	189·2
1896	211	208	223	262	227	215	207	194	179	181	190	191	207·3
1897	173	191	230	264	256	245	233	213	174	179	203	217	214·8
1898	217	235	248	259	249	233	211	199	192	205	216	218	223·5
1899	195	195	234	265	253	243	213	187	180	185	198	215	213·6
1900	214	216	227	268	246	236	227	206	194	195	218	225	222·7
Average— 1861-1900	214·6	220·6	250·2	289·5	282·2	270·2	250·2	228·1	218·3	215·7	223·6	232·5	241·3
1901	191	184	234	294	256	238	217	207	196	185	197	217	218·0
1902	191	193	248	253	241	258	268	234	212	209	204	215	227·2
1903	217	237	273	286	257	256	253	232	233	207	200	191	236·8
1904	183	229	283	329	302	284	265	245	231	218	197	196	246·8
1905	181	181	221	276	258	276	269	246	235	219	217	234	234·4
1906	233	208	220	258	249	252	242	210	200	220	237	255	232·0
1907	237	216	236	277	270	262	252	232	230	238	238	259	245·6
1908	244	241	261	320	313	286	259	229	200	197	199	197	245·5
1909	192	215	244	298	304	264	242	219	203	198	196	205	231·7
1910	187	219	249	262	265	242	228	217	203	202	199	199	222·7
1911	190	196	218	248	239	228	211	195	190	194	210	222	211·8
1912	201	193	246	304	294	274	231	227	226	231	239	260	243·8
1913	256	246	276	322	284	273	249	221	211	215	226	220	249·9
1914	211	204	237	300	262	245	225	220	211	196	196	192	224·9
1915	204	214	208	217	224	219	234	239	218	204	203	216	216·7
1916	229	219	240	311	320	307	257	217	201	199	203	207	242·5
1917	192	201	253	296	274	295	283	247	230	243	242	220	248·0
1918	198	233	274	279	254	248	234	223	225	229	235	238	239·2
1919	226	218	246	301	329	297	250	231	215	216	215	204	245·7
1920	172	181	219	254	231	234	236	222	215	217	225	239	220·4
1921	217	219	259	282	262	239	220	201	195	197	199	210	225·0
1922	192	201	256	302	278	267	251	215	201	198	181	184	227·2
1923	183	197	234	261	255	243	211	195	187	181	195	224	213·8
1924	214	196	216	273	275	247	232	216	208	197	184	179	219·8
1925	163	215	249	243	221	208	199	190	184	191	214	207	207·0
Average— 1901-1925	204·2	210·2	244·0	281·8	268·7	257·7	240·7	221·2	210·4	208·0	210·0	215·6	231·1
1861-1925	210·6	216·6	247·8	286·6	277·0	265·4	246·6	225·4	215·3	212·8	218·4	2226·0	237·4

TABLE 7—LOCAL SUPPLY TO LAKE ONTARIO

In Thousand Second Feet

—	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Average
1861	25	60	63	94	110	64	47	27	40	68	47	38	56·9
1862	−8	25	75	117	85	52	42	14	6	16	32	46	41·8
1863	24	12	40	99	76	51	20	15	28	27	51	45	39·9
1864	7	20	59	113	107	66	32	22	35	45	66	86	54·8
1865	70	50	59	84	75	62	33	8	9	21	29	30	44·2
1866	6	7	33	62	43	81	82	44	37	32	39	46	42·7
1867	20	65	101	131	112	69	29	16	12	−5	−5	0	45·4
1868	15	12	56	86	75	60	23	23	10	16	40	55	40·0
1869	24	22	24	100	92	76	68	54	48	46	57	90	58·4
1870	62	41	71	132	91	49	46	16	11	18	17	34	49·0
1871	13	27	64	89	65	41	23	12	5	10	7	16	31·0
1872	−14	−22	22	60	56	52	33	25	16	23	23	13	23·9
1873	11	20	101	143	66	43	34	14	9	16	43	70	47·5
1874	56	54	56	47	48	56	39	13	2	10	11	16	34·0
1875	−11	−14	52	84	58	44	30	17	6	14	17	30	27·3
1876	55	55	66	104	78	60	35	5	−1	20	12	11	41·7
1877	−22	10	57	75	47	40	30	5	−9	1	25	34	24·4
1878	19	36	56	59	49	34	32	27	19	26	71	83	42·6
1879	9	18	36	74	57	47	29	12	9	4	25	41	30·1
1880	34	36	40	53	53	51	20	−1	9	15	27	10	28·9
1881	−18	28	62	56	43	39	21	−5	−3	14	27	45	25·8
1882	33	39	50	50	57	58	26	8	−3	−10	0	15	26·9
1883	0	−4	30	73	96	89	59	15	4	10	27	33	36·0
1884	25	52	74	80	50	35	34	24	12	6	19	38	37·4
1885	13	−10	28	85	90	60	40	19	17	26	43	62	39·4
1886	39	47	77	99	65	34	18	17	21	14	28	36	41·3
1887	39	87	56	81	75	37	16	0	−1	3	7	2	33·5
1888	−17	−4	41	65	41	39	27	11	1	7	24	30	22·1
1889	25	14	37	62	65	63	44	9	1	3	42	79	37·0
1890	51	50	52	72	87	69	22	13	24	35	37	20	44·3
1891	19	56	75	78	52	31	23	13	−1	−15	4	28	30·3
1892	11	10	36	58	47	62	46	20	9	3	15	12	27·4
1893	−4	13	57	119	110	50	18	17	20	3	13	36	37·7
1894	33	19	45	57	71	58	13	−3	3	8	1	6	25·9
1895	−4	−7	20	68	38	18	7	−5	−8	−18	12	30	12·6
1896	36	35	57	87	40	30	16	−2	−7	2	9	15	26·5
1897	−10	15	46	67	51	38	28	10	−21	−7	16	28	21·8
1898	30	51	55	54	41	26	6	−5	−2	14	21	25	26·3
1899	3	13	37	73	57	40	13	−6	−8	4	18	25	23·3
1900	24	31	38	73	43	34	24	8	−1	7	26	35	28·6
Average— 1861–1900	18·1	27·0	52·9	81·4	66·6	50·2	30·7	13·2	9·0	13·3	25·6	34·9	35·2
1901	11	10	66	120	79	50	26	18	7	1	16	35	36·6
1902	8	24	77	70	51	61	58	25	10	6	4	25	34·9
1903	22	48	75	73	44	40	38	23	27	3	4	−5	32·7
1904	8	46	90	114	77	54	38	26	16	10	−6	−3	39·2
1905	−9	1	41	86	57	59	46	28	21	10	16	30	32·2
1906	28	13	31	62	47	44	33	2	−3	19	33	50	29·9
1907	19	6	36	65	54	39	26	11	17	22	24	48	30·6
1908	26	34	51	97	85	57	32	8	−15	−5	−2	−1	30·6
1909	6	23	53	99	88	42	22	6	−1	−1	6	20	30·3
1910	2	41	59	64	55	33	21	18	6	5	6	10	26·7
1911	7	18	40	64	44	31	16	4	7	6	16	27	23·3
1912	11	15	68	102	84	66	23	19	15	28	32	56	43·3
1913	48	31	69	82	46	34	16	−3	0	10	17	12	30·2
1914	9	9	52	99	47	27	13	9	7	−2	−4	4	22·5
1915	24	32	22	32	34	25	32	33	15	2	4	24	23·3
1916	23	14	41	101	98	80	31	−1	−12	−13	1	8	30·9
1917	−2	11	61	86	52	61	42	12	4	18	20	2	30·6
1918	−5	38	70	78	52	39	20	12	10	22	23	24	32·8
1919	13	9	38	79	96	61	18	4	−6	6	3	−2	26·6
1920	−12	8	42	65	29	25	22	12	9	14	22	30	22·2
1921	14	19	60	67	43	19	5	−9	−10	0	8	6	18·5
1922	−5	17	70	101	64	50	35	7	−2	1	−15	−2	26·8
1923	−1	19	54	73	60	43	14	1	0	−2	16	35	26·0
1924	13	12	34	80	71	40	22	12	8	4	−8	−7	23·4
1925	−1	47	74	61	38	47	18	12	9	8	36	29	31·5
Average— 1901-1925	10·3	21·8	55·0	80·8	59·8	45·1	26·7	11·6	5·6	6·9	10·9	18·6	29·4
1861-1925	15·1	25·0	53·7	81·1	64·0	48·2	29·2	12·5	7·6	10·8	19·9	28·6	33·0

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete	
	Monthly mean		First of mean	Monthly mean	First of mean	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1860—						
January	602·69	94	...	...	602·80	81
February	602·44	88	...	...	602·61	80
March	602·42	87	...	...	602·48	103
April	602·69	93	...	...	602·56	120
May	602·92	102	...	...	602·73	122
June	603·09	106	...	...	602·87	122
July	603·05	106	...	...	602·88	83
August	603·10	108	...	...	602·96	109
September	603·08	106	...	...	602·97	109
October	603·12	107	...	...	602·97	109
November	602·95	102	...	...	602·90	106
December	602·60	93	...	...	602·62	103
1861—						
January	602·40	87	...	...	602·32	78
February	602·15	81	...	...	602·13	76
March	602·01	78	...	...	601·93	51
April	602·42	87	...	...	602·14	79
May	603·05	105	...	...	602·68	122
June	603·20	109	...	...	603·02	125
July	603·36	113	...	...	603·12	126
August	603·32	113	...	...	603·15	127
September	603·23	109	...	...	603·25	112
October	603·26	110	...	...	603·20	111
November	602·92	102	...	...	603·05	108
December	602·54	92	...	...	602·66	103
1862—						
January	602·19	83	...	...	602·27	51
February	602·00	78	...	...	602·09	51
March	602·03	79	...	...	602·07	51
April	602·09	79	...	...	602·20	79
May	602·77	98	...	...	602·57	120
June	602·76	99	...	...	602·84	122
July	602·73	99	...	...	602·74	82
August	602·90	103	...	...	602·87	109
September	603·02	104	...	...	603·00	109
October	602·95	103	...	...	603·00	108
November	602·62	95	...	...	602·79	105
December	602·35	87	...	...	602·45	101
1863—						
January	602·16	82	...	...	602·19	51
February	602·03	79	...	...	602·12	76
March	601·86	75	...	...	601·95	51
April	601·90	75	...	...	601·96	51
May	602·03	81	...	...	602·12	51
June	601·95	80	...	...	602·23	51
July	602·09	84	...	...	602·34	52
August	602·71	99	...	...	602·82	109
September	602·73	98	...	...	603·11	110
October	602·56	94	...	...	603·00	108
November	602·21	85	...	...	602·70	104
December	602·10	82	...	...	602·41	101
1864—						
January	601·81	74	...	...	602·15	51
February	601·60	69	...	...	601·97	51
March	601·67	70	...	...	601·95	51
April	601·69	70	...	...	602·05	51
May	601·85	77	...	...	602·19	52

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland†Canal complete	
	Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1864—						
June	602·00	81	....	....	602·43	52
July	602·09	84	....	....	602·63	81
August	602·10	84	....	....	602·69	81
September	602·25	86	....	....	602·76	106
October	601·99	81	....	....	602·64	103
November	601·80	76	....	....	602·35	100
December	601·65	71	....	....	602·10	76
1865—						
January	601·47	66	....	....	601·93	51
February	601·46	65	....	....	601·88	50
March	601·33	62	....	....	601·84	51
April	601·77	72	....	....	602·03	51
May	602·26	87	....	....	602·55	121
June	602·67	96	....	....	602·90	125
July	602·99	105	....	....	603·18	127
August	603·07	107	....	....	603·31	128
September	603·08	106	....	....	603·30	112
October	602·87	101	....	....	603·17	109
November	602·34	88	....	....	602·78	104
December	602·03	80	....	....	602·31	99
1866—						
January	601·74	72	....	....	601·96	51
February	601·53	67	....	....	601·77	50
March	601·53	67	....	....	601·70	50
April	601·98	77	....	....	601·98	51
May	602·23	86	....	....	602·40	80
June	602·42	91	....	....	602·64	82
July	602·71	98	....	....	602·90	84
August	602·94	104	....	....	603·21	126
September	602·67	96	....	....	603·12	110
October	602·69	97	....	....	602·95	108
November	602·36	89	....	....	602·77	105
December	602·47	90	....	....	602·60	104
1867—						
January	602·20	83	....	....	602·48	79
February	602·09	80	....	....	602·31	78
March	601·90	76	....	....	602·14	77
April	602·12	80	....	....	602·16	78
May	602·12	83	....	....	602·21	52
June	602·72	98	....	....	602·66	83
July	603·05	106	....	....	603·17	127
August	602·93	104	....	....	603·22	126
September	603·01	104	....	....	603·13	111
October	602·99	104	....	....	603·14	110
November	602·56	93	....	....	602·90	105
December	602·24	85	....	....	602·48	101
1868—						
January	602·08	80	....	....	602·19	51
February	601·49	66	....	....	601·91	51
March	601·85	74	....	....	601·83	51
April	602·04	78	....	....	602·18	78
May	602·44	91	....	....	602·47	80
June	602·35	89	....	....	602·66	81
July	602·57	95	....	....	602·74	82
August	602·49	93	....	....	602·85	108
September	602·62	95	....	....	602·84	108

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete	
	Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1868—						
October	602·59	94	....	....	602·84	108
November	602·75	98	....	....	602·87	107
December	602·32	87	....	....	602·70	103
1869—						
January	602·10	81	602·68	78	602·33	78
February	601·86	75	602·47	80	602·11	76
March	601·41	64	602·04	60	601·74	50
April	601·99	77	602·18	101	601·85	51
May	602·39	90	602·60	119	602·41	80
June	602·40	90	602·72	52	602·65	81
July	602·77	100	603·03	50	602·86	84
August	603·23	111	603·58	132	603·32	132
September	604·08	129	604·16	139	603·92	137
October	603·56	117	604·29	141	604·05	135
November	603·22	109	603·79	122	603·57	113
December	602·57	93	603·25	50	603·06	107
1870—						
January	602·32	86	602·93	50	602·57	79
February	602·11	80	602·82	55	602·36	78
March	602·12	81	602·78	96	602·24	78
April	602·22	82	602·79	94	602·31	116
May	602·55	93	602·98	72	602·42	80
June	602·36	89	603·10	50	602·53	80
July	602·55	95	603·22	50	602·55	52
August	602·55	95	603·44	50	602·77	106
September	602·72	97	603·66	70	602·83	107
October	602·56	94	603·74	112	602·80	106
November	602·38	89	603·52	125	602·59	101
December	601·45	67	602·85	50	602·00	50
1871—						
January	601·36	74	602·41	50	601·54	49
February	600·76	71	602·15	50	601·27	49
March	601·18	64	602·10	50	601·23	50
April	601·68	68	602·60	119	601·73	51
May	602·21	81	602·96	124	602·29	52
June	602·33	90	603·15	127	602·71	120
July	602·40	90	603·14	55	602·71	81
August	602·46	93	603·31	89	602·80	107
September	602·56	94	603·40	130	602·84	107
October	602·49	89	603·30	128	602·81	106
November	602·42	85	603·13	126	602·69	103
December	601·68	75	602·69	59	602·22	76
1872—						
January	601·47	69	602·17	62	601·75	50
February	601·36	67	602·04	85	601·65	50
March	601·24	62	601·87	71	601·58	50
April	601·14	61	601·73	50	601·50	50
May	601·79	82	602·05	70	601·81	51
June	602·17	85	602·57	50	602·42	52
July	602·44	95	603·03	125	602·84	83
August	602·61	102	603·14	126	603·09	111
September	602·77	104	603·23	128	603·24	112
October	602·67	100	603·18	121	603·24	111
November	602·52	97	603·02	125	603·08	109
December	602·22	87	602·69	121	602·82	106
1873—						
January	602·12	77	602·40	117	602·56	79

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete	
	Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1873—						
February	601·80	73	602·07	80	602·35	78
March	601·82	74	601·87	50	602·16	78
April	601·87	74	602·00	50	602·18	78
May	602·31	87	602·32	50	602·41	80
June	602·61	90	602·78	80	602·81	123
July	602·90	100	603·12	93	603·00	125
August	603·08	106	603·32	129	603·17	127
September	603·14	108	603·41	111	603·23	112
October	603·04	105	603·37	91	603·19	111
November	602·90	100	603·31	92	603·05	109
December	602·60	94	603·11	63	602·80	104
1874—						
January	602·14	82	602·83	53	602·39	78
February	602·13	78	602·68	50	602·17	77
March	602·09	75	602·73	121	602·13	77
April	602·19	73	602·63	120	602·15	78
May	602·26	82	602·58	89	602·22	52
June	602·46	92	602·67	50	602·45	52
July	602·84	101	603·10	113	602·85	83
August	602·93	102	603·29	128	603·14	126
September	603·03	102	603·31	107	603·17	112
October	603·09	105	603·37	127	603·21	111
November	602·91	99	603·25	128	603·13	110
December	602·60	97	602·93	81	602·85	105
1875—						
January	602·28	87	602·82	85	602·51	79
February	602·24	81	602·47	118	602·36	78
March	602·28	80	602·37	117	602·34	101
April	602·28	86	602·28	116	602·30	116
May	602·50	93	602·32	50	602·32	79
June	602·86	100	602·73	87	602·65	82
July	602·85	102	602·93	54	602·87	83
August	602·94	102	603·12	50	602·97	109
September	603·17	108	603·42	122	603·11	111
October	603·02	105	603·43	112	603·14	110
November	602·88	99	603·26	74	602·98	109
December	602·68	86	603·16	119	602·78	105
1876—						
January	602·48	85	602·87	81	602·52	79
February	602·27	84	602·68	60	602·34	78
March	602·18	78	602·60	71	602·20	78
April	602·21	79	602·59	66	602·17	78
May	602·75	96	602·92	102	602·45	82
June	603·43	109	603·48	131	603·11	128
July	603·82	120	603·98	137	603·57	133
August	603·93	121	604·17	140	603·78	134
September	603·82	122	604·11	82	603·74	132
October	603·49	114	604·01	87	603·48	113
November	603·33	108	603·84	88	603·24	111
December	603·05	96	603·67	103	603·02	108
1877—						
January	602·69	90	603·34	...	602·67	80
February	602·45	91	...	...	602·40	78
March	602·19	88	...	...	602·16	77
April	602·11	85	...	...	602·03	51
May	602·10	85	...	...	602·08	51
June	602·32	90	...	...	602·29	52

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete	
	Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1877—						
July	602·70	98	...	...	602·69	82
August	602·76	100	...	...	602·96	108
September	602·60	95	...	...	602·89	107
October	602·60	96	...	...	602·77	105
Nov	602·39	90	...	...	602·64	101
Dec	602·32	87	...	...	602·46	102
1878—						
January	602·20	82	...	...	602·33	78
February	602·32	76	...	...	602·34	78
March	601·55	73	...	...	602·23	77
April	601·52	73	...	...	602·18	78
May	601·79	79	...	...	602·28	52
June	602·07	85	...	...	602·64	81
July	602·14	88	...	...	602·82	82
August	602·02	87	...	...	602·82	105
September	601·85	80	...	...	602·62	104
October	601·92	83	...	...	602·49	102
November	601·72	81	...	...	602·37	100
December	601·40	76	...	...	602·05	51
1879—						
January	601·49	67	...	...	602·01	51
February	601·46	57	...	...	602·09	51
March	601·76	52	...	...	602·23	77
April	601·37	55	...	...	602·11	50
May	601·01	63	...	...	601·75	50
June	601·24	67	...	...	601·72	51
July	601·48	73	...	...	602·00	51
August	601·60	74	...	...	602·25	78
September	601·49	72	...	...	602·25	78
October	601·58	73	...	...	602·22	78
November	601·50	69	...	...	602·21	76
December	601·14	60	...	...	601·97	50
1880—						
January	600·99	55	...	...	601·74	50
February	600·98	54	...	...	601·68	50
March	600·89	52	...	...	601·63	50
April	600·92	52	...	...	601·61	50
May	601·52	70	...	...	601·93	51
June	602·30	87	...	...	602·68	83
July	602·45	93	...	...	603·15	126
August	602·44	90	...	...	603·12	125
September	602·44	93	...	...	603·01	109
October	602·39	88	...	...	602·94	108
November	602·33	89	...	...	602·83	106
December	602·07	82	...	...	602·61	103
1881—						
January	601·81	75	...	...	602·29	51
February	601·71	73	...	...	602·19	77
March	601·62	73	...	...	602·06	51
April	601·53	71	...	...	602·04	51
May	601·83	81	...	...	602·20	52
June	602·27	86	...	...	602·66	82
July	602·33	90	...	...	602·92	106
August	602·38	89	...	...	602·93	109
September	602·61	93	...	...	603·01	110
October	602·95	104	...	...	603·24	113
November	602·88	101	...	...	603·35	112
December	602·60	94	...	...	603·14	109

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete	
	Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1882—						
January	602·25	82	......	......	602·78	81
February	602·00	77	......	......	602·49	79
March	601·89	74	......	......	602·28	78
April	601·81	73	......	......	602·18	78
May	601·97	82	......	......	602·20	51
June	601·99	84	......	......	602·38	52
July	602·44	93	......	......	602·71	82
August	602·56	95	......	......	603·03	110
September	602·60	93	......	......	603·07	109
October	602·43	91	......	......	602·95	108
November	602·41	90	......	......	602·81	106
December	602·22	84	......	......	602·65	104
1883—						
January	601·99	74	......	......	602·38	78
February	601·70	72	......	......	602·11	76
March	601·70	72	......	......	601·94	51
April	601·95	73	......	......	602·13	78
May	601·96	73	......	......	602·24	52
June	602·06	82	......	......	602·36	52
July	602·31	86	......	......	602·62	81
August	602·33	96	......	......	602·77	106
September	602·29	88	......	......	602·73	105
October	602·09	84	......	......	602·55	103
November	601·94	82	......	......	602·33	100
December	601·83	76	......	......	602·14	51
1884—						
January	601·80	74	......	......	602·14	51
February	601·63	69	......	......	602·10	76
March	601·54	67	......	......	601·94	51
April	601·32	63	......	......	601·84	51
May	601·54	72	......	......	601·87	51
June	601·74	74	......	......	602·15	51
July	601·88	79	......	......	602·38	52
August	601·89	80	......	......	602·54	80
September	602·16	82	......	......	602·68	106
October	602·52	84	......	......	602·92	109
November	602·42	86	......	......	602·98	108
December	602·21	80	......	......	602·75	105
1885—						
January	601·98	76	......	......	602·46	79
February	601·80	74	......	......	602·25	77
March	601·72	70	......	......	602·09	51
April	601·67	67	......	......	602·09	51
May	602·00	80	......	......	602·27	52
June	602·28	88	......	......	602·66	82
July	602·52	92	......	......	602·93	124
August	602·64	97	......	......	603·02	109
September	602·57	91	......	......	603·01	108
October	602·40	87	......	......	602·84	106
November	602·25	86	......	......	602·62	103
December	601·92	79	......	......	602·33	99
1886—						
January	601·72	71	......	......	602·00	51
February	601·59	67	......	......	601·90	50
March	601·53	67	......	......	601·84	51
April	601·62	67	......	......	601·90	51
May	601·87	78	......	......	602·11	51

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete	
	Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1886—						
June	602·01	81	...	...	602·39	52
July	602·08	85	...	...	602·58	52
August	601·99	88	...	...	602·67	81
September	601·97	85	...	...	602·64	105
October	602·07	86	...	...	602·61	104
November	601·92	84	...	...	602·54	102
December	601·78	74	...	...	602·33	100
1887—						
January	601·47	69	...	...	602·03	51
February	601·49	66	...	...	601·95	51
March	601·80	65	...	...	602·14	78
April	601·97	62	...	...	602·35	115
May	601·76	71	...	...	602·16	51
June	601·92	81	...	...	602·20	52
July	602·20	90	...	...	602·50	52
August	602·28	87	...	...	602·79	106
September	602·14	84	...	...	602·71	105
October	602·07	88	...	...	602·54	102
November	601·83	82	...	...	602·34	100
December	601·61	73	...	...	602·05	51
1888—						
January	601·50	69	...	...	601·96	51
February	601·51	61	...	...	601·96	51
March	601·44	62	...	...	601·95	51
April	601·44	62	...	...	601·96	51
May	601·91	76	...	...	602·22	52
June	602·69	96	...	...	602·92	125
July	602·88	99	...	...	603·31	129
August	603·02	99	...	...	603·39	129
September	602·97	97	...	...	603·35	127
October	602·88	97	...	...	603·19	110
November	602·74	93	...	...	603·03	108
December	602·39	78	...	...	602·74	104
1889—						
January	602·07	72	...	...	602·33	78
February	601·85	66	...	...	602·04	51
March	601·68	67	...	...	601·88	51
April	601·69	67	...	...	601·85	51
May	602·04	78	...	...	602·07	51
June	602·16	82	...	...	602·39	52
July	602·35	87	...	...	602·63	82
August	602·54	87	...	...	602·84	108
September	602·67	87	...	...	602·94	108
October	602·51	84	...	...	602·86	106
November	620·20	78	...	...	602·56	102
December	601·90	70	...	...	602·18	51
1890—						
January	601·76	71	...	...	602·02	51
February	601·63	60	...	...	601·95	50
March	601·39	60	...	...	601·78	50
April	601·36	59	...	...	601·67	50
May	601·57	68	...	...	601·79	51
June	602·02	80	...	...	602·17	52
July	602·32	87	...	...	602·62	81
August	602·47	85	...	...	602·87	108
September	602·60	83	...	...	602·94	108
October	602·57	82	...	...	602·92	107

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete	
	Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1890—						
November	602·36	79	....	....	602·72	105
December	602·00	73	....	....	602·36	100
1891—						
January	601·64	59	....	....	601·92	50
February	601·51	61	....	....	601·70	50
March	601·47	58	....	....	601·63	50
April	601·43	62	....	....	601·62	50
May	601·63	71	....	....	601·73	50
June	601·68	70	....	....	601·92	51
July	601·88	72	....	....	602·10	51
August	601·86	72	....	....	602·25	77
September	601·82	71	....	....	602·21	78
October	601·91	72	....	....	602·21	77
November	601·79	70	....	....	602·18	76
December	601·42	63	....	....	601·91	50
1892—						
January	601·42	62	....	....	601·76	50
February	601·14	55	....	....	601·66	49
March	601·01	51	....	....	601·47	49
April	601·02	54	....	....	601·41	50
May	601·35	65	....	....	601·59	50
June	601·73	72	....	....	601·79	51
July	601·76	75	....	....	602·06	51
August	601·88	75	....	....	602·20	78
September	601·93	76	....	....	602·28	78
October	601·83	74	....	....	602·24	77
November	601·66	68	....	....	602·10	51
December	601·38	63	....	....	601·92	50
1893—						
January	601·10	52	....	....	601·68	50
February	601·01	49	....	....	601·51	49
March	601·06	49	....	....	601·47	50
April	601·16	54	....	....	601·55	50
May	601·66	65	....	....	601·86	51
June	602·18	75	....	....	602·41	52
July	602·48	78	....	....	602·88	83
August	602·54	80	....	....	603·05	109
September	602·45	77	....	....	602·95	108
October	602·42	76	....	....	602·80	106
November	602·26	75	....	....	602·61	103
December	602·03	65	....	....	602·33	100
1894—						
January	601·85	61	602·69	70	602·03	51
February	601·67	59	602·48	56	601·88	50
March	601·76	57	602·43	119	601·84	51
April	601·91	64	602·36	111	601·98	51
May	602·69	83	602·70	120	602·48	81
June	602·91	88	603·08	126	602·99	125
July	602·97	90	603·12	56	603·02	125
August	603·10	90	603·32	96	603·01	109
September	603·02	88	603·32	99	602·98	109
October	603·04	89	603·25	78	602·89	107
November	602·99	87	603·27	128	602·82	106
December	602·80	81	603·03	124	602·64	103
1895—						
January	602·50	75	602·60	92	602·33	77
February	602·28	73	602·34	95	602·07	51

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete	
	Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1895—						
March	602·11	69	602·06	60	601·92	50
April	602·01	68	601·96	50	601·84	51
May	602·38	76	602·16	50	602·02	51
June	602·70	84	602·57	119	602·45	52
July	602·90	88	602·73	121	602·79	82
August	602·95	88	602·75	121	602·94	109
September	603·09	92	602·75	121	602·98	109
October	603·14	94	602·66	120	603·02	109
November	602·85	84	602·57	119	602·85	105
December	602·52	81	602·15	79	602·48	101
1896—						
January	602·32	71	601·88	50	602·15	51
February	602·12	71	601·75	50	602·01	51
March	601·92	67	601·60	50	601·86	51
April	602·01	69	601·59	50	601·86	51
May	602·66	80	602·03	112	602·28	52
June	603·04	88	602·44	117	602·88	123
July	603·10	91	602·58	95	602·99	123
August	603·12	91	602·60	74	602·93	109
September	602·95	89	602·58	56	602·81	105
October	602·63	82	602·43	50	602·51	102
November	602·70	83	602·38	50	602·32	100
December	602·55	80	602·45	70	602·22	77
1897—						
January	602·39	75	602·33	97	602·08	51
February	602·16	69	602·12	60	601·96	50
March	602·08	70	601·93	50	601·84	50
April	602·11	71	601·94	50	601·88	51
May	602·45	79	602·21	50	602·12	51
June	602·78	86	602·63	86	602·54	81
July	603·08	91	602·95	119	602·86	83
August	603·20	93	603·07	80	603·10	110
September	603·14	90	603·13	70	603·08	109
October	602·94	87	603·07	78	602·89	110
November	602·64	86	602·84	50	602·57	102
December	602·21	76	602·57	50	602·16	76
1898—						
January	601·83	67	602·25	56	601·76	50
February	601·65	62	602·04	50	601·53	50
March	601·46	59	601·87	50	601·36	49
April	601·46	62	601·80	50	601·30	50
May	601·70	69	601·93	50	601·45	50
June	602·18	77	602·35	50	601·87	51
July	602·59	82	602·89	123	602·38	52
August	602·72	84	603·03	101	602·74	106
September	602 82	85	603·10	95	602·80	106
October	602·76	83	603·08	72	602·75	105
November	602·56	81	602·99	50	602·55	102
December	602·33	80	602 86	72	602·27	77
1899—						
January	601·96	69	602·59	68	601·98	51
February	601·76	67	602·31	50	601·75	50
March	601·79	66	602·27	91	601·70	50
April	601·76	64	602·18	92	601·75	51
May	602·47	82	602·47	118	602·12	52
June	602·96	89	602·95	124	602·82	123
July	603·19	94	603·21	124	603·07	126

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system, assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete	
	Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1899—						
August	603·35	96	603·31	80	603·17	127
September	603·51	100	603·33	131	603·24	112
October	603·32	95	603·41	129	603·19	110
November	603·21	92	603·17	80	603·00	108
December	603·00	89	603·03	125	602·78	105
1900—						
January	602·63	79	602·63	70	602·45	78
February	602·45	76	602·38	85	602·18	76
March	602·23	72	602·15	58	601·96	51
April	602·13	72	602·03	50	601·87	51
May	602·30	76	602·13	50	601·96	51
June	602·36	78	602·32	50	602·15	52
July	602·58	82	602·54	50	602·36	52
August	602·94	86	602·89	110	602·75	108
September	603·46	94	603·43	131	603·12	112
October	603·54	95	603·49	131	603·36	113
November	603·51	95	603·40	130	603·34	112
December	603·13	85	603·09	75	603·08	108
1901—						
January	602·78	80	602·77	77	602·65	80
February	602·48	75	602·45	68	602·33	78
March	602·28	68	602·18	52	602·05	51
April	602·22	70	602·11	50	601·97	51
May	602·51	76	602·24	50	602·14	52
June	602·61	79	602·56	50	602·41	52
July	603·09	87	602·94	124	602·77	83
August	603·22	90	603·13	126	603·09	110
September	603·04	87	603·00	50	603·01	108
October	603·07	78	603·03	50	602·87	107
November	603·00	78	603·10	126	602·77	105
December	602·68	72	602·75	62	602·49	101
1902—						
January	602·32	67	602·45	50	602·07	51
February	602·11	62	602·22	61	601·83	51
March	601·97	57	601·98	57	601·67	50
April	602·02	61	601·93	50	601·65	51
May	602·34	66	602·15	50	601·86	51
June	602·64	70	602·50	63	602·22	52
July	602·88	74	602·80	60	602·54	52
August	602·89	76	602·96	50	602·73	106
September	602·93	77	603·07	59	602·67	104
October	602·81	75	603·07	74	602·54	103
November	602·81	75	603·02	50	602·40	101
December	602·58	70	602·97	115	602·21	76
1903—						
January	602·24	65	602·56	57	601·90	51
February	601·98	61	602·30	50	601·65	50
March	601·88	60	602·13	50	601·49	50
April	602·07	62	602·22	84	601·56	50
May	602·56	70	602·48	118	601·93	51
June	602·94	78	602·78	122	602·42	52
July	603·14	80	602·94	74	602·79	82
August	603·25	81	603·11	50	602·94	108
September	603·27	80	603·26	54	602·92	108
October	603·40	81	603·42	87	602·91	108
November	603·18	81	603·36	129	602·79	104
December	602·80	74	602·90	59	602·42	100

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system; assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system; assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete	
	Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1904—						
January	602·50	72	602·61	64	602·00	51
February	602·33	71	602·41	78	601·83	51
March	602·23	67	602·24	81	601·75	50
April	602·17	71	602·15	50	601·72	51
May	602·47	76	602·33	50	601·89	51
June	602·77	82	602·70	50	602·27	52
July	602·86	85	602·99	50	602·55	52
August	602·95	87	603·17	50	602·74	106
September	603·08	88	603·40	115	602·79	107
October	603·26	91	603·48	50	602·89	108
November	603·19	88	603·65	133	602·89	106
December	602·74	82	603·25	128	602·57	102
1905—						
January	602·47	78	602·77	53	602·15	51
February	602·13	71	602·54	100	601·93	51
March	602·04	67	602·23	74	601·76	51
April	602·25	74	602·27	124	601·87	51
May	602·49	80	602·35	55	602·16	52
June	602·67	83	602·62	50	602·46	52
July	602·97	88	602·96	50	602·78	82
August	603·10	88	603·28	114	603·01	110
September	603·32	89	603·37	113	603·13	111
October	603·33	94	603·42	130	603·17	110
November	603·17	89	603·23	124	603·05	108
December	602·96	84	602·94	90	602·80	105
1906—						
January	602·72	82	602·70	69	602·52	79
February	602·43	77	602·48	50	602·27	77
March	602·22	74	602·29	50	602·00	51
April	602·15	76	602·21	50	601·93	51
May	602·48	82	602·43	76	602·13	52
June	602·78	86	602·76	122	602·53	81
July	602·90	89	602·87	64	602·75	82
August	602·93	88	603·02	50	602·85	107
September	602·95	88	603·15	76	602·82	106
October	602·84	87	603·13	83	602·72	105
November	602·66	85	602·98	50	602·52	102
December	602·45	79	602·90	50	602·27	77
1907—						
January	602·22	74	602·76	59	602·06	51
February	602·06	71	602·62	91	601·94	51
March	601·94	66	602·40	108	601·84	51
April	601·94	71	602·21	57	601·83	51
May	602·10	73	602·34	50	601·96	51
June	602·55	79	602·71	75	602·33	52
July	602·70	85	603·03	69	602·71	82
August	602·93	89	603·26	94	602·91	109
September	603·17	93	603·50	131	603·09	110
October	603·15	89	603·50	130	603·14	110
November	602·88	88	603·20	50	602·94	106
December	602·53	82	603·00	64	602·56	101
1908—						
January	602·10	75	602·66	50	602·12	51
February	601·87	69	602·43	51	601·86	51
March	601·72	65	602·27	77	601·72	50
April	601·63	62	602·12	50	601·65	50
May	602·03	68	602·30	50	601·83	51

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system; assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system; assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete	
	Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1908—						
June	602·57	79	602·82	122	602·36	52
July	602·85	88	603·12	127	602·84	83
August	602·92	89	603·19	59	603·03	109
September	602·77	86	603·23	67	602·94	107
October	602·59	82	603·11	79	602·70	104
November	602·23	80	602·87	77	602·37	100
December	601·99	75	602·56	83	602·00	51
1909—						
January	601·69	67	602·27	61	601·81	50
February	601·46	60	602·02	50	601·60	50
March	601·35	53	601·87	50	601·44	50
April	601·29	54	601·81	50	601·37	50
May	601·62	59	601·93	50	601·51	50
June	601·94	68	602·30	50	601·86	51
July	602·18	73	602·63	50	602·19	52
August	602·40	82	602·93	66	602·49	80
September	602·40	83	603·07	98	602·60	104
October	602·29	80	602·98	103	602·48	102
November	602·26	73	602·83	99	602·35	101
December	602·26	79	602·75	79	602·24	78
1910—						
January	602·01	71	602·63	77	602·13	51
February	601·74	66	602·35	84	601·93	51
March	601·51	62	602·03	50	601·71	50
April	601·62	60	602·00	50	601·68	51
May	601·75	62	602·15	50	601·83	51
June	601·90	69	602·33	50	602·00	51
July	601·88	72	602·45	50	602·12	51
August	601·97	73	602·55	50	602·22	78
September	601·96	74	602·66	50	602·25	78
October	601·92	73	602·70	50	602·21	77
November	601·68	69	602·63	50	602·06	51
December	601·41	62	602·43	51	601·85	50
1911—						
January	601·07	55	602·15	59	601·58	50
February	600·89	51	601·87	50	601·34	49
March	600·66	49	601·65	50	601·13	49
April	600·54	50	601·48	50	600·96	49
May	600·82	54	601·57	50	601·04	49
June	601·27	56	601·93	50	601·42	50
July	601·62	59	602·36	65	601·83	51
August	602·09	62	602·74	121	602·27	79
September	602·18	62	602·85	123	602·50	80
October	602·18	62	602·73	64	602·48	102
November	602·03	61	602·63	50	602·29	78
December	601·90	57	602·53	50	602·10	51
1912—						
January	601·76	56	602·41	50	601·99	51
February	601·53	54	602·23	78	601·82	50
March	601·43	53	602·00	50	601·66	50
April	601·45	54	601·98	50	601·63	50
May	601·90	59	602·22	50	601·87	51
June	602·20	63	602·63	58	602·27	52
July	602·35	63	602·87	50	602·53	52
August	602·53	67	603·07	50	602·73	106
September	602·65	68	603·26	50	602·76	106
October	602·60	69	603·35	53	602·68	104

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system; assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system; assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete	
	Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1912—						
November	602·44	69	603·22	60	602·47	101
December	602·20	65	603·11	53	602·17	76
1913—						
January	601·89	62	602·89	82	601·87	50
February	601·57	61	602·52	50	601·59	50
March	601·51	58	602·58	73	601·42	50
April	601·64	62	602·57	50	601·48	50
May	602·07	67	602·65	50	601·79	51
June	602·36	69	603·05	125	602·20	52
July	602·64	71	603·18	79	602·53	52
August	602·78	73	603·36	73	602·80	106
September	602·83	75	603·46	93	602·80	107
October	603·02	78	603·56	131	602·86	107
November	602·88	76	603·39	125	602·75	105
December	602·70	73	603·07	67	602·50	101
1914—						
January	602·40	71	602·87	82	602·18	51
February	602·21	68	602·59	98	602·00	51
March	601·92	65	602·23	52	601·79	50
April	601·84	64	602·08	50	601·65	51
May	602·23	69	602·29	59	601·84	51
June	602·46	72	602·63	83	602·21	52
July	602·68	73	602·83	50	602·49	52
August	602·75	75	603·03	56	602·70	81
September	602·81	78	603·16	74	602·74	105
October	602·73	89	603·14	58	602·65	104
November	602·45	87	603·07	99	602·43	100
December	602·09	70	602·72	66	602·06	51
1915—						
January	601·82	66	602·41	50	601·81	50
February	601,69	67	602·26	82	601·65	50
March	601·47	66	602·03	50	601·51	50
April	601·32	63	601·90	50	601·37	50
May	601·61	70	602·01	50	601·48	50
June	601·92	72	602·36	85	601·83	51
July	602·25	77	602·65	50	602·21	52
August	602·36	78	602·94	124	602·50	80
September	602·40	76	602·87	50	602·57	105
October	602·73	75	603·15	127	602·66	106
November	602·81	77	603·19	127	602·78	106
December	602·69	73	603·03	125	602·66	104
1916—						
January	602·60	70	602·76	93	602·46	79
February	602·41	69	602·58	100	602·30	77
March	602·15	69	602·24	50	602·04	51
April	602·34	74	602·27	75	602·06	52
May	602·96	83	602·67	121	602·53	121
June	603·43	99	603·09	126	602·96	125
July	603·60	99	603·33	71	603·20	126
August	603·69	105	603·56	83	603·25	128
September	603·81	117	603·73	134	603·29	112
October	603·64	119	603·64	133	603·27	111
November	603·45	116	603·43	73	603·12	109
December	603·13	110	603·28	54	602·87	106
1917—						
January	602·75	91	603·12	126	602·54	79
February	602·42	88	602·67	51	602·22	77

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system; assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system; assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete	
	Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1917—						
March	602·33	86	602·55	119	602·02	51
April	602·28	90	602·37	88	602·06	51
May	602·38	92	602·41	50	602·19	52
June	602·60	91	602·68	50	602·47	52
July	602·65	87	602·94	50	602·72	81
August	602·69	76	603·10	50	602·78	106
September	602·73	74	603·21	50	602·73	105
October	602·67	78	603·28	69	602·63	103
November	602·46	74	603·17	55	602·42	100
December	602·16	59	602·97	57	602·09	51
1918—						
January	601·93	60	602·73	72	601·85	50
February	601·71	58	602·46	56	601·65	50
March	601·61	59	602·30	50	601·50	50
April	601·46	58	602·20	50	601·41	50
May	601·74	59	602·29	50	601·49	50
June	602·10	65	602·63	50	601·84	51
July	602·26	58	602·94	53	602·14	51
August	602·42	61	603·11	50	602·32	79
September	602·54	67	603·28	82	602·41	79
October	602·49	69	603·27	84	602·41	102
November	602·55	64	603·23	103	602·32	100
December	602·43	55	603·08	67	602·17	67
191 —						
January	602·28	55	602·94	90	601·98	51
February	602·09	53	602·65	97	601·82	50
March	601·90	53	602·31	50	601·62	50
April	602·03	53	602·29	54	601·60	50
May	602·26	55	602·47	50	601·79	51
June	602·46	53	602·68	50	602·02	51
July	602·60	54	602·88	50	602·19	51
August	602·60	52	602·96	50	602·27	78
September	602·56	55	602·95	50	602·17	77
October	602·48	55	602·90	50	602·05	51
November	602·50	56	602·89	50	602·03	51
December	602·32	56	602·69	60	601·96	51
1920—						
January	602·07	57	602·59	58	601·77	50
February	601·90	56	602·38	87	601·58	50
March	601·91	56	602·20	98	601·51	50
April	602·25	55	602·25	115	601·70	51
May	602·39	74	602·32	50	601·95	51
June	602·74	77	602·60	65	602·26	52
July	602·93	81	602·94	86	602·60	81
August	602·96	100	603·04	50	602·71	105
September	602·80	81	603 12	50	602·64	104
October	602·68	59	603·07	50	602·42	101
November	602·47	58	602·93	50	602·13	76
December	602·24	55	602·73	50	601·85	51
1921—						
January	602·07	53	602·54	50	601·67	59
February	601·75	54	602·30	50	601·43	49
March	601·54	52	602·03	50	601·17	49
April	601·68	53	602·00	50	601·14	49
May	602·11	48	602·30	50	601·43	50
June	602·42	46	602·66	50	601·80	51
July	602·58	54	602·88	74	602·01	51

TABLE 9—EFFECT OF REGULATION—LAKE SUPERIOR—*Concluded*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Complete regulation system; assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete		Partial regulation system; assuming 8,500 cfs. diversion at Chicago and new Welland Canal complete	
	Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)
1921—						
August	602·76	54	602·98	91	602·19	51
September	602·69	56	602·93	50	602·26	77
October	602·55	55	602·82	50	602·09	51
November	602·22	48	602·59	50	601·87	50
December	602·01	45	602·33	50	601·59	50
1922—						
January	601·64	42	602·03	50	601·28	49
February	601·45	44	601·72	50	600·99	49
March	601·33	44	601·57	50	600·81	49
April	601·47	44	601·55	50	600·81	49
May	601·96	44	601·85	50	601·10	49
June	602·22	41	602·20	50	601·46	50
July	602·51	43	602·45	50	601·71	51
August	602·65	44	602·65	50	601·90	51
September	602·72	43	602·74	50	601·99	51
October	602·52	47	602·65	50	601·90	51
November	602·37	48	602·46	50	601·72	50
December	602·10	48	602·23	50	601·50	49
1923—						
Januar	601·88	48	602·00	50	601·25	49
February	601·62	49	601·75	50	601·01	49
March	601·47	51	601·53	50	600·79	48
April	601·41	51	601·43	50	600·70	48
May	601·67	55	601·53	50	600·80	49
June	601·69	54	601·67	50	600·96	49
July	601·97	53	601·85	50	601·13	49
August	602·08	53	602·04	50	601·33	50
September	602·12	52	602·13	50	601·42	50
October	602·09	50	602·04	50	601·43	50
November	602·05	49	602·10	50	601·40	49
December	601·80	50	601·94	50	601·25	49
1924—						
January	601·58	50	601·72	50	601·02	49
February	601·35	50	601·44	50	600·80	48
March	601·09	51	601·23	50	600·55	48
April	601·04	52	601·09	50	600·41	48
May	601·22	53	601·15	50	600·48	48
June	601·30	50	601·30	50	600·63	48
July	601·41	47	601·39	50	600·73	49
August	601·67	50	601·57	50	600·91	49
September	601·91	49	601·73	50	601·16	49
October	601·91	50	601·93	50	601·28	49
November	601·77	51	601·86	50	601·21	49
December	601·52	50	601·67	50	601·02	49
1925—						
January	601·15	52	601·36	50	600·62	48
February	601·00	51	601·11	50	600·39	47
March	600·83	52	600·88	50	600·29	47
April	600·88	54	600·88	50	600·23	47
May	600·97	55	600·97	50	600·33	48
June	601·25	53	601·17	50	600·56	48
July	601·42	53	601·40	50	600·82	49
August	601·52	57	601·55	50	600·99	49
September	601·43	62	601·58	50	601·02	49
October	601·41	66	601·55	50	601·00	49
November	601·14	63	601·44	50	600·83	48
December	600·90	59	601·24	50	600·60	48

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (h)	Discharge (i)
1860—								
January	582·51	214	581·36	206	....	....	581·50	195
February	582·69	154	581·54	145	....	....	581·49	137
March	582·72	194	581·57	186	....	....	581·59	175
April	582·85	200	581·70	191	....	....	581·74	181
May	582·97	213	581·82	205	....	....	581·94	195
June	583·09	231	581·94	222	....	....	582·13	210
July	583·13	240	581·98	232	....	....	582·27	234
August	582·94	237	581·79	228	....	....	582·16	231
September	582·74	235	581·59	227	....	....	581·97	228
October	582·43	218	581·28	209	....	....	581·71	221
November	582·10	221	580·95	213	....	....	581·38	217
December	581·94	209	580·79	199	....	....	581·13	193
1861—								
January	581·83	204	580·68	196	....	....	581·03	194
February	581·92	184	580·77	175	....	....	581·03	168
March	582·31	219	581·16	211	....	....	581·26	198
April	582·41	213	581·26	204	....	....	581·48	198
May	582·83	218	581·68	210	....	....	581·73	201
June	582·99	226	581·84	217	....	....	582·09	208
July	583·12	230	581·97	222	....	....	582·29	236
August	583·36	235	582·21	226	....	....	582·48	237
September	583·05	229	581·90	221	....	....	582·45	236
October	582·93	228	581·78	219	....	....	582·22	231
November	582·70	223	581·55	215	....	....	582·03	228
December	582·53	219	581·38	210	....	....	581·82	224
1862—								
January	582·33	208	581·18	200	....	....	581·63	194
February	582·18	169	581·03	160	....	....	581·43	155
March	582·48	221	581·33	213	....	....	581·44	200
April	582·64	213	581·49	204	....	....	581·65	200
May	582·89	220	581·74	212	....	....	581·85	204
June	583·02	223	581·87	214	....	....	582·21	209
July	582·92	220	581·77	212	....	....	582·28	232
August	582·91	222	581·76	213	....	....	582·23	231
September	582·84	223	581·69	215	....	....	582·17	228
October	582·73	224	581·58	215	....	....	582·05	229
November	582·34	217	581·19	209	....	....	581·80	224
December	582·20	214	581·05	205	....	....	581·52	219
1863—								
January	582·13	210	580·98	202	....	....	581·42	195
February	582·18	209	581·03	200	....	....	581·38	194
March	582·17	201	581·02	193	....	....	581·39	187
April	582·17	207	581·02	198	....	....	581·35	193
May	582·38	211	581·23	203	....	....	581·41	195
June	582·47	215	581·32	206	....	....	581·51	196
July	582·42	212	581·27	204	....	....	581·50	196
August	582·29	210	581·14	201	....	....	581·37	195
September	582·11	208	580·96	200	....	....	581·25	194
October	582·02	212	580·87	203	....	....	581·15	193
November	581·58	203	580·43	195	....	....	580·95	193
December	581·92	211	580·77	202	....	....	580·94	193
1864—								
January	581·69	204	580·54	196	....	....	581·06	193

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system, assuming 8,500 cfs diversion at Chicago and New Welland Canal complete		Partial regulation system, assuming 8,500 cfs diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1864—								
February	581·55	207	580·40	198	…	…	580·84	190
March	581·80	209	580·65	201	…	…	580·87	189
April	581·51	195	580·36	186	…	…	580·85	185
May	582·02	203	580·87	195	…	…	580·91	186
June	582·01	200	580·86	191	…	…	581·15	188
July	581·91	201	580·76	193	…	…	581·03	188
August	581·73	199	580·58	190	…	…	580·91	185
September	581·46	194	580·31	186	…	…	580·70	183
October	581·07	191	579·92	182	…	…	580·41	178
November	580·90	187	579·75	179	…	…	580·19	176
December	580·77	181	579·62	172	…	…	580·11	173
1865—								
January	580·56	165	579·41	157	…	…	579·94	152
February	580·65	155	579·50	146	…	…	579·87	137
March	580·82	191	579·67	183	…	…	579·98	179
April	581·31	198	580·16	189	…	…	580·30	180
May	581·47	195	580·32	187	…	…	580·60	182
June	581·51	196	580·36	187	…	…	580·79	185
July	581·94	206	580·79	198	…	…	581·09	194
August	581·96	207	580·81	198	…	…	581·38	197
September	581·84	205	580·69	197	…	…	581·38	197
October	581·60	202	580·45	193	…	…	581·21	192
November	581·04	193	579·89	185	…	…	580·84	186
December	580·73	186	579·58	177	…	…	580·43	179
1866—								
January	580·47	179	579·32	171	…	…	580·19	176
February	580·23	180	579·08	171	…	…	579·89	170
March	580·28	181	579·13	173	…	…	579·76	171
April	580·73	183	579·58	174	…	…	579·98	171
May	580·91	185	579·76	177	…	…	580·26	175
June	581·20	189	580·05	180	…	…	580·50	178
July	581·46	193	580·31	185	…	…	580·75	184
August	581·52	196	580·37	187	…	…	580·89	185
September	581·37	193	580·22	185	…	…	580·90	187
October	581·26	190	580·11	181	…	…	580·81	185
November	581·17	190	580·02	182	…	…	580·73	185
December	580·91	180	579·76	171	…	…	580·58	181
1867—								
January	580·89	192	579·74	184	…	…	580·45	181
February	580·94	193	579·79	184	…	…	580·48	180
March	581·12	176	579·97	168	…	…	580·57	164
April	581·41	196	580·26	187	…	…	580·82	186
May	581·63	197	580·48	189	…	…	581·08	190
June	581·94	199	580·79	190	…	…	581·28	192
July	582·09	207	580·94	199	…	…	581·49	197
August	582·02	204	580·87	195	…	…	581·58	198
September	581·75	203	580·60	195	…	…	581·45	198
October	581·42	198	580·27	189	…	…	581·16	192
November	580·96	192	579·81	184	…	…	580·78	186
December	580·61	183	579·46	174	…	…	580·39	179
1868—								
January	580·45	182	579·30	174	…	…	580·17	178
February	580·41	173	579·26	164	…	…	580·01	164

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system, assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system, assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1868—								
March	581·09	196	579·94	188	....	....	580·29	184
April	580·99	189	579·84	180	....	....	580·55	183
May	581·27	190	580·12	182	....	....	580·63	183
June	581·48	192	580·33	183	....	....	580·87	184
July	581·51	194	580·36	186	....	....	580·97	185
August	581·17	189	580·02	180	....	....	580·79	182
September	580·93	186	579·78	178	....	....	580·47	180
October	580·70	185	579·55	176	....	....	580·27	177
November	580·63	187	579·48	179	....	....	580·14	176
December	580·35	180	579·20	171	....	....	579·99	172
1869—								
January	580·25	183	579·10	175	580·75	163	579·84	172
February	580·32	171	579·17	162	580·74	198	579·83	158
March	580·06	167	578·91	159	580·60	150	579·74	159
April	580·43	179	579·28	170	580·63	108	579·77	167
May	580·76	184	579·61	176	581·17	203	580·08	172
June	581·29	193	580·14	184	581·59	172	580·50	179
July	581·67	196	580·52	188	582·00	227	580·95	187
August	581·93	204	580·78	195	582·12	225	581·25	192
September	581·82	204	580·67	196	582·18	238	581·11	190
October	581·46	198	580·31	189	581·88	198	580·90	188
November	581·34	197	580·19	189	581·68	214	580·71	186
December	581·06	189	579·91	180	581·47	165	580·53	181
1870—								
January	581·12	178	579·97	170	581·30	150	580·45	178
February	581·21	180	580·06	171	581·34	150	580·50	166
March	581·51	186	580·36	178	581·54	203	580·69	169
April	581·93	203	580·78	194	581·88	231	581·07	192
May	582·27	207	581·12	199	582·21	175	581·35	199
June	582·41	211	581·26	202	582·45	192	581·75	200
July	582·52	211	581·37	203	582·52	244	581·85	203
August	582·43	209	581·28	200	582·37	191	581·79	203
September	582·57	216	581·42	208	582·31	241	581·84	205
October	582·17	212	581·02	203	582·05	237	581·73	201
November	581·77	203	580·62	195	581·64	230	581·37	196
December	581·42	192	580·27	183	581·27	219	581·03	191
1871—								
January	581·57	206	580·42	198	581·08	203	580·88	191
February	581·49	174	580·34	165	581·03	187	580·88	188
March	582·09	210	580·94	202	581·23	221	581·09	197
April	582·29	213	581·14	204	581·56	226	581·48	200
May	582·64	219	581·49	211	581·86	232	581·72	204
June	582·68	219	581·53	210	582·12	237	581·88	206
July	582·71	220	581·56	212	582·29	240	582·00	208
August	582·48	217	581·33	208	581·88	233	581·90	204
September	581·81	201	580·66	193	581·45	150	581·48	194
October	581·12	190	579·97	181	580·94	150	580·83	185
November	581·07	191	579·92	183	580·75	154	580·50	182
December	580·48	175	579·33	166	580·55	180	580·22	175
1872—								
January	580·36	182	579·20	174	580·15	151	579·87	172
February	580·35	183	579·20	174	580·10	204	579·77	171
March	580·13	182	578·98	174	579·96	183	579·62	171

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system, assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system, assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1872—								
April	580·38	182	579·23	173	580·00	169	579·62	171
May	580·63	187	579·48	179	580·21	174	579·84	175
June	581·00	191	579·85	182	580·52	150	580·12	176
July	581·03	194	579·88	186	580·71	168	580·26	178
August	581·01	192	579·86	183	580·80	176	580·26	176
September	580·94	192	579·79	184	580·85	195	580·26	178
October	580·82	188	579·67	179	580·77	186	580·19	176
November	580·52	187	579·38	179	580·60	169	580·02	172
December	579·87	172	578·72	163	580·21	150	579·59	166
1873—								
January	579·87	178	578·72	170	579·98	174	579·30	166
February	579·91	176	578·76	167	580·08	192	579·34	166
March	580·22	179	579·07	171	580·11	185	579·51	173
April	580·79	183	579·64	174	580·56	156	579·96	175
May	581·35	197	580·20	189	581·14	150	580·53	189
June	581·98	211	580·83	202	581·70	229	581·12	198
July	581·94	208	580·79	200	581·95	233	581·50	199
August	582·04	211	580·89	202	581·90	231	581·59	200
September	581·85	208	580·70	200	581·81	231	581·59	203
October	581·79	210	580·64	201	581·65	230	581·48	200
November	581·56	206	580·41	198	581·43	227	581·36	199
December	581·52	202	580·37	193	581·21	183	581·24	194
1874—								
January	581·48	164	580·33	156	581·12	182	581·23	160
February	581·77	136	580·62	127	581·15	144	581·34	128
March	581·92	197	580·77	189	581·27	150	581·55	188
April	581·82	204	580·67	195	581·49	210	581·59	196
May	581·80	200	580·65	192	581·50	150	581·54	199
June	582·17	215	581·02	206	581·77	168	581·64	200
July	582·10	211	580·95	203	581·90	231	581·73	202
August	582·11	212	580·96	203	581·85	227	581·66	201
September	581·86	215	580·71	207	581·75	230	581·61	202
October	581·51	211	580·36	202	581·57	229	581·49	200
November	581·31	200	580·16	192	581·21	212	581·18	195
December	580·97	203	579·82	194	581·00	212	580·96	192
1875—								
January	580·77	201	579·62	193	580·75	213	580·82	191
February	580·70	201	579·55	192	580·56	210	580·66	189
March	580·76	200	579·61	192	580·60	212	580·64	191
April	581·12	198	579·97	189	580·60	210	580·86	196
May	581·68	207	580·53	199	581·19	184	581·27	201
June	581·92	214	580·77	205	581·50	167	581·62	203
July	581·89	216	580·74	208	581·71	153	581·77	205
August	582·06	216	580·91	207	581·81	208	581·82	206
September	581·99	219	580·84	211	581·75	230	581·87	228
October	581·84	216	580·69	207	581·62	229	581·74	224
November	581·63	215	580·48	207	581·43	228	581·57	223
December	581·44	201	580·29	192	581·14	213	581·35	192
1876—								
January	581·39	203	580·24	200	581·06	208	581·29	198
February	581·59	204	580·44	195	581·22	174	581·37	196
March	581·92	197	580·77	189	581·28	150	581·50	197
April	582·12	205	580·97	196	581·58	163	581·72	199

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system, assuming 8,500 c.f.s diversion at Chicago and New Welland Canal complete		Partial regulation system, assuming 8,500 c.f.s diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1876—								
May	582·74	199	581·59	191	582·04	214	582·14	192
June	583·15	226	582·00	217	582·54	244	582·65	219
July	583·49	237	582·34	229	582·94	252	583·10	251
August	583·42	238	582·27	229	583·07	259	583·25	253
September	583·37	241	582·22	233	582·98	255	583·17	252
October	582·79	234	581·64	225	582·57	249	582·86	245
November	582·89	231	581·74	223	582·21	243	582·58	242
December	582·42	241	581·27	205	581·96	238	582·36	236
1877—								
January	582·28	213	581·13	205	581·65	....	582·06	212
February	582·29	197	581·14	188	....	....	581·93	186
March	582·29	148	581·14	140	....	....	581·87	139
April	582·67	177	581·52	168	....	....	581·96	165
May	582·56	182	581·41	174	....	....	582·02	170
June	582·63	226	581·48	217	....	....	581·99	207
July	582·60	227	581·45	219	....	....	581·98	207
August	582·48	226	581·33	217	....	....	581·96	207
September	582·27	222	581·12	214	....	....	581·83	227
October	582·28	218	581·13	209	....	....	581·67	224
November	582·16	216	581·01	208	....	....	581·60	223
December	582·10	215	580·95	206	....	....	581·52	219
1878—								
January	581·98	209	580·83	201	....	....	581·45	194
February	581·91	164	580·76	155	....	....	581·35	152
March	582·07	195	580·92	187	....	....	581·37	180
April	582·09	205	580·94	196	....	....	581·47	197
May	582·39	214	581·24	206	....	....	581·65	201
June	582·53	220	581·38	211	....	....	581·86	203
July	582·54	219	581·39	211	....	....	581·96	206
August	582·22	218	581·07	209	....	....	581·87	204
September	582·02	214	580·87	206	....	....	581·70	204
October	581·91	217	580·76	208	....	....	581·61	222
November	581·78	216	580·63	208	....	....	581·52	220
December	581·46	192	580·31	183	....	....	581·33	199
1879—								
January	581·15	185	580·00	177	....	....	581·00	172
February	581·16	159	580·01	150	....	....	580·78	168
March	581·20	188	580·05	180	....	....	580·70	177
April	581·19	197	580·04	188	....	....	580·78	185
May	581·32	194	580·17	186	....	....	580·84	186
June	581·39	200	580·24	191	....	....	580·94	187
July	581·48	200	580·33	192	....	....	580·99	189
August	581·29	199	580·14	190	....	....	580·91	188
September	581·17	200	580·02	192	....	....	580·80	187
October	580·95	197	579·80	188	....	....	580·66	185
November	580·73	197	579·58	189	....	....	580·49	184
December	580·76	194	579·61	185	....	....	580·43	181
1880—								
January	580·80	192	579·65	184	....	....	580·45	186
February	580·71	185	579·56	176	....	....	580·43	173
March	580·75	191	579·60	183	....	....	580·39	177
April	580·92	189	579·77	180	....	....	580·45	179
May	581·26	196	580·11	188	....	....	580·68	186

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system, assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system, assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1880—								
June	581·77	205	580·62	196	....	....	581·09	192
July	581·99	211	580·84	203	....	....	581·47	200
August	582·02	210	580·87	201	....	....	581·67	201
September	581·72	210	580·57	202	....	....	581·62	201
October	581·38	205	580·23	196	....	....	581·38	198
November	581·06	204	579·91	196	....	....	581·14	194
December	580·89	192	579·74	181	....	....	580·98	192
1881—								
January	580·90	186	579·75	178	....	....	580·89	179
February	581·11	″02	579·96	193	....	....	580·96	188
March	581·40	196	580·25	188	....	....	581·18	186
April	581·31	205	580·16	196	....	....	581·21	193
May	581·82	208	580·67	200	....	....	581·36	197
June	582·05	209	580·90	200	....	....	581·62	199
July	582·02	214	580·87	206	....	....	581·75	202
August	582·02	210	580·87	201	....	....	581·79	204
September	581·79	209	580·64	201	....	....	581·69	206
October	582·12	219	580·97	210	....	....	581·76	228
November	581·95	225	580·80	217	....	....	581·89	230
December	581·85	210	580·70	201	....	....	581·80	220
1882—								
January	581·63	208	580·48	200	....	....	581·65	201
February	581·62	195	580·47	186	....	....	581·50	188
March	581·99	203	580·84	195	....	....	581·55	199
April	582·12	207	580·97	198	....	....	581·77	201
May	582·22	206	581·07	198	....	....	581·93	205
June	582·49	214	581·34	205	....	....	582·05	205
July	582·62	211	581·47	203	....	....	582·17	210
August	582·81	213	581·66	204	....	....	582·28	233
September	582·69	219	581·54	211	....	....	582·26	233
October	582·28	217	581·13	208	....	....	582·03	227
November	582·07	213	580·92	205	....	....	581·76	224
December	581·74	203	580·59	194	....	....	581·51	219
1883—								
January	581·48	204	580·33	196	....	....	581·28	197
February	581·52	208	580·37	199	....	....	581·18	195
March	581·61	187	581·46	179	....	....	581·21	177
April	581·82	206	580·67	197	....	....	581·26	196
May	582·30	217	581·15	209	....	....	581·59	204
June	582·66	219	581·51	210	....	....	582·03	209
July	583·26	223	582·11	215	....	....	582·43	238
August	583·23	230	582·08	221	....	....	582·69	239
September	583·04	227	581·89	219	....	....	582·61	238
October	582·82	223	581·67	214	....	....	582·33	233
November	582·37	232	581·22	224	....	....	582·12	233
December	582·29	221	581·14	212	....	....	582·01	225
1884—								
January	582·07	166	580·92	158	....	....	581·79	152
February	582·19	179	581·04	170	....	....	581·66	165
March	582·44	215	581·29	207	....	....	581·74	205
April	582·62	221	581·47	212	....	....	581·92	206
May	582·83	225	581·68	217	....	....	582·13	209
June	582·99	224	581·84	215	....	....	582·27	210

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system, assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system, assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1884—								
July	582·83	226	581·68	218	....	....	582·28	232
August	582·69	226	581·54	217	....	....	582·11	227
September	582·44	222	581·29	214	....	....	581·88	227
October	582·44	229	581·29	220	....	....	581·79	226
November	582·08	224	580·93	216	....	....	581·71	225
December	582·05	214	580·90	205	....	....	581·49	201
1885—								
January	582·06	215	580·91	207	....	....	581·56	206
February	582·29	223	581·14	214	....	....	581·67	208
March	582·25	212	581·10	204	....	....	581·69	207
April	582·44	215	581·29	206	....	....	581·72	205
May	582·80	228	581·65	220	....	....	581·96	209
June	583·01	232	581·86	223	....	....	582·24	212
July	583·10	235	581·95	227	....	....	582·41	238
August	583·31	237	582·16	228	....	....	582·60	241
September	583·17	236	582·02	228	....	....	582·64	242
October	583·03	234	581·88	225	....	....	582·49	237
November	582·73	229	581·58	221	....	....	582·30	233
December	582·44	222	581·29	213	....	....	582·07	231
1886—								
January	582·67	182	581·52	174	....	....	582·01	171
February	582·69	162	581·54	153	....	....	582·07	151
March	582·97	202	581·82	194	....	....	582·16	190
April	583·24	209	582·09	200	....	....	582·40	196
May	583·50	233	582·35	225	....	....	582·67	218
June	583·57	245	582·42	236	....	....	582·82	222
July	583·38	241	582·23	233	....	....	582·74	243
August	583·15	238	582·00	229	....	....	582·48	237
September	582·91	235	581·76	227	....	....	582·26	235
October	582·81	233	581·66	224	....	....	582·11	231
November	582·47	230	581·32	222	....	....	581·93	228
December	582·14	218	580·99	209	....	....	581·64	222
1887—								
January	582·06	217	580·92	209	....	....	581·45	202
February	582·43	221	581·29	212	....	....	581·52	201
March	582·59	201	581·45	193	....	....	581·71	185
April	582·54	210	581·40	201	....	....	581·82	193
May	582·74	216	581·60	208	....	....	582·02	204
June	582·87	226	581·73	217	....	....	582·15	208
July	582·81	229	581·67	221	....	....	582·17	210
August	582·67	225	581·53	216	....	....	582·05	228
September	582·33	219	581·19	211	....	....	581·81	224
October	581·88	217	580·74	208	....	....	581·49	198
November	581·55	211	580·41	203	....	....	581·19	194
December	581·43	204	580·29	195	....	....	580·94	189
1888—								
January	581·25	200	580·11	192	....	....	580·75	187
February	581·20	200	580·06	191	....	....	580·62	185
March	581·38	193	580·24	185	....	....	580·65	176
April	581·59	204	580·45	195	....	....	580·83	188
May	581·97	201	580·83	193	....	....	581·11	185
June	582·24	221	581·10	212	....	....	581·43	198
July	582·25	218	581·11	210	....	....	581·67	203

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system, assuming 8,500 c.f.s diversion at Chicago and New Welland Canal complete		Partial regulation system, assuming 8,500 c.f.s diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge h)
1888—								
August	582·13	220	580·99	211	....	....	581·75	203
September	581·98	216	580·84	208	....	....	581·71	204
October	581·73	211	580·59	202	....	....	581·53	220
November	581·68	208	580·54	200	....	....	581·34	216
December	581·10	201	579·96	192	....	....	581·08	189
1889—								
January	581·08	197	579·94	189	....	....	580·91	191
February	581·05	176	579·91	167	....	....	580·87	166
March	581·03	176	579·89	168	....	....	580·78	163
April	581·04	180	579·90	171	....	....	580·74	169
May	581·12	192	579·98	184	....	....	580·76	180
June	581·58	203	580·44	194	....	....	580·96	189
July	581·76	207	580·62	199	....	....	581·22	193
August	581·52	208	580·38	199	....	....	581·27	193
September	581·35	206	580·21	198	....	....	581·17	193
October	581·10	201	579·96	192	....	....	580·98	189
November	580·75	195	579·61	187	....	....	580·71	186
December	580·57	186	579·43	177	....	....	580·50	177
1890—								
January	580·65	188	579·51	180	....	....	580·43	179
February	580·61	185	579·47	176	....	....	580·40	174
March	580·59	180	579·45	172	....	....	580·30	171
April	580·91	185	579·77	176	....	....	580·40	174
May	581·14	187	580·00	179	....	....	580·64	177
June	581·55	196	580·41	187	....	....	580·95	184
July	581·62	202	580·48	194	....	....	581·18	190
August	581·54	205	580·40	196	....	....	581·23	192
September	581·34	201	580·20	193	....	....	581·16	193
October	581·23	198	580·09	189	....	....	581·02	190
November	580·89	194	579·75	186	....	....	580·87	186
December	580·54	187	579·40	178	....	....	580·62	183
1891—								
January	580·52	181	579·38	173	....	....	580·45	177
February	580·28	185	579·14	176	....	....	580·30	175
March	580·47	163	579·33	155	....	....	580·20	159
April	580·78	184	579·64	175	....	....	580·38	175
May	580·88	186	579·74	178	....	....	580·61	175
June	581·03	198	579·89	189	....	....	580·68	183
July	580·86	198	579·72	190	....	....	580·64	183
August	580·79	197	579·65	188	....	....	580·55	181
September	580·56	194	579·42	186	....	....	580·43	180
October	580·20	188	579·06	179	....	....	580·17	174
November	579·80	182	578·66	174	....	....	579·84	172
December	579·74	181	578·60	172	....	....	579·66	169
1892—								
January	579·86	174	578·79	166	....	....	579·65	165
February	580·05	150	578·98	141	....	....	579·70	142
March	579·95	156	578·88	148	....	....	579·70	148
April	580·01	177	578·94	168	....	....	579·74	169
May	580·43	180	579·36	172	....	....	579·91	171
June	580·88	186	579·81	177	....	....	580·25	173
July	580·89	192	579·82	184	....	....	580·54	178
August	580·97	196	579·90	187	....	....	580·62	180

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system, assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system, assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1892—								
September......	580·77	192	579·70	184	....	....	580·60	182
October..........	580·53	192	579·46	183	....	....	580·41	178
November......	580·26	190	579·19	182	....	....	580·16	176
December......	579·99	180	578·92	171	....	....	579·87	169
1893—								
January..........	579·98	155	578·97	147	....	....	579·65	139
February........	580·12	157	579·11	148	....	....	579·63	142
March...........	580·23	180	579·22	172	....	....	579·70	172
April............	580·69	184	579·68	175	....	....	579·96	174
May.............	580·99	184	579·98	176	....	....	580·40	166
June.............	581·32	199	580·31	190	....	....	580·79	183
July.............	581·34	202	580·33	194	....	....	580·96	188
Aug.............	581·17	201	580·16	192	....	....	580·96	189
September......	580·85	196	579·84	188	....	....	580·81	188
October..........	580·71	195	579·70	186	....	....	580·63	189
November......	580·32	192	579·31	184	....	....	580·47	183
December......	580·25	186	579·24	177	....	....	580·29	179
1894—								
January..........	580·26	189	579·31	181	580·73	153	580·30	179
February........	580·29	175	579·34	166	580·82	181	580·29	163
March...........	580·55	188	579·60	180	580·90	210	580·37	175
April............	580·70	185	579·75	176	581·15	206	580·57	172
May.............	581·24	195	580·29	187	581·52	215	580·89	184
June.............	581·40	209	580·45	200	581·86	229	581·24	194
July.............	581·43	212	580·48	204	582·03	232	581·49	199
August...........	581·35	208	280·40	199	581·90	232	581·54	199
September......	580·92	205	579·97	197	581·60	173	581·34	197
October..........	580·71	201	579·76	192	581·40	162	581·12	193
November......	580·44	200	579·49	192	581·23	222	580·93	190
December......	580·09	191	579·14	182	580·97	217	580·71	185
1895—								
January..........	579·91	178	578·99	170	580·72	213	580·47	182
February........	579·80	174	578·88	165	580·47	169	580·28	179
March...........	579·77	183	578·85	175	580·44	181	580·12	178
April............	579·97	172	579·05	163	580·48	150	580·15	162
May.............	580·13	179	579·21	171	580·62	150	580·27	168
June.............	580·18	193	579·26	184	580·73	180	580·35	179
July.............	580·07	191	579·15	183	580·82	192	580·29	178
August...........	579·95	189	579·03	180	580·77	177	580·20	176
September......	579·68	187	578·76	179	580·70	181	580·11	175
October..........	579·31	185	578·39	176	580·49	183	579·89	171
November......	579·09	178	578·17	170	580·35	204	579·62	168
December......	578·98	170	578·06	161	579·98	150	579·43	166
1896—								
January..........	579·06	171	578·18	163	579·95	150	579·42	166
February........	579·10	147	578·22	138	580·02	170	579·46	137
March...........	579·11	158	578·23	150	579·90	150	579·42	151
April............	579·29	168	578·41	159	579·90	150	579·42	163
May.............	579·57	170	578·69	162	580·10	150	579·60	162
June.............	579·89	184	579·01	175	580·52	150	579·90	172
July.............	579·83	184	578·95	176	580·82	183	580·15	176
August...........	579·76	182	578·88	173	580·81	150	580·21	175
September......	579·66	182	578·78	174	580·75	150	580·18	176

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system, assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system, assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1896—								
October	579·61	179	578·73	170	580·60	170	580·08	174
November	579·39	181	578·51	173	580·37	171	579·97	174
December	579·34	173	578·46	164	580·19	169	579·87	168
1897—								
January	579·33	176	578·48	168	580·20	160	579·85	172
February	579·41	169	578·56	160	580·21	187	579·80	169
March	579·72	173	578·87	165	580·25	150	579·83	170
April	579·89	175	579·04	166	580·47	150	580·03	166
May	580·38	183	579·53	175	580·87	153	580·38	173
June	580·65	196	579·80	187	581·24	183	580·73	184
July	580·84	199	579·99	191	581·48	194	580·95	189
August	580·78	200	579·93	191	581·62	173	581·02	190
September	580·53	196	579·68	188	581·49	163	580·93	189
October	580·24	192	579·39	183	581·20	178	580·68	185
November	579·98	190	579·13	182	580·94	174	580·47	182
December	579·76	183	578·91	174	580·65	150	580·27	178
1898—								
January	579·72	180	578·90	172	580·49	150	580·11	176
February	579·86	156	579·04	147	580·51	150	580·08	151
March	580·18	177	579·36	169	580·68	150	580·22	172
April	580·50	181	579·68	172	581·04	210	580·54	172
May	580·78	182	579·96	174	581·25	152	580·82	175
June	580·91	195	580·09	186	581·42	150	580·95	186
July	580·89	197	580·07	189	581·54	185	581·00	189
August	580·69	196	579·87	187	581·57	169	580·89	188
September	580·34	195	579·52	187	581·44	163	580·72	186
October	580·33	190	579·51	181	581·30	182	560·56	183
November	579·92	189	579·10	181	581·07	150	580·41	180
December	579·58	183	578·76	174	580·82	150	580·20	175
1899—								
January	579·53	177	578·73	169	580·65	162	579·99	168
February	579·61	177	578·81	168	580·57	166	579·87	166
March	579·81	113	579·01	105	580·62	134	579·89	90
April	580·08	164	579·28	155	580·81	150	580·09	157
May	580·52	192	579·72	184	581·24	204	580·42	181
June	580·83	199	580·03	190	581·70	227	580·79	188
July	581·04	205	580·24	197	582·00	233	581·17	195
August	580·96	203	580·16	194	582·07	236	581·33	198
September	580·82	201	580·02	193	581·82	232	581·26	196
October	580·49	195	579·69	186	581·53	225	581·01	191
November	580·31	193	579·51	185	581·28	220	580·78	188
December	579·81	184	579·01	175	580·92	210	580·55	186
1900—								
January	579·66	137	578·88	132	580·67	155	580·33	132
February	579·77	125	578·99	119	580·54	150	580·27	118
March	579·94	130	579·16	125	580·59	146	580·35	135
April	580·07	176	579·29	170	580·62	150	580·41	171
May	580·31	180	579·53	175	580·78	150	580·53	175
June	580·42	189	579·64	183	580·95	150	580·65	182
July	580·53	194	579·75	189	581·12	151	580·76	187
August	580·70	193	579·92	187	581·27	208	580·86	190
September	580·65	196	579·87	191	581·37	201	580·99	193
October	580·66	197	579·88	191	581·42	224	581·01	193

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
	Stage (b)	Discharg (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (h)	Discharge (i)
(a)								
1900—								
November	580·52	198	579·74	193	581·37	224	581·00	193
December	580·19	189	579·41	183	581·22	217	580·88	182
1901—								
January	579·95	160	579·24	156	580·87	176	580·67	155
February	579·92	107	579·21	102	580·67	120	580·52	102
March	580·34	130	579·63	126	580·68	146	580·58	128
April	580·49	126	579·78	121	580·87	150	580·81	120
May	580·92	174	580·21	170	581·09	157	581·10	189
June	580·97	203	580·26	198	581·27	177	581·27	198
July	581·06	204	580·35	200	581·36	177	581·31	199
August	581·11	206	580·40	210	581·57	215	581·39	198
September	580·92	200	580·21	196	581·53	182	581·37	198
October	580·56	198	579·85	193	581·25	156	581·17	193
November	580·23	196	579·52	192	560·98	196	580·95	191
December	579·95	158	579·24	153	580·77	155	580·71	154
1902—								
January	579·76	115	579·09	111	580·53	129	580·55	111
February	579·61	122	578·94	117	580·32	134	580·36	116
March	579·84	176	579·17	172	580·28	150	580·29	174
April	579·91	178	579·24	173	589·42	150	580·38	175
May	580·30	187	579·63	183	580·66	150	580·57	185
June	580·50	191	579·83	186	580·98	164	580·84	187
July	580·83	190	580·16	186	581·30	150	581·08	191
August	580·85	194	580·18	189	581·53	150	581·21	191
September	580·48	189	579·81	185	581·41	150	581·13	191
October	580·33	184	579·66	179	581·17	150	580·91	187
November	580·22	185	579·55	181	581·08	171	580·80	187
December	579·93	176	579·26	171	580·85	210	580·66	176
1903—								
January	579·72	124	579·08	121	580·65	146	580·44	123
February	579·90	119	579·26	115	580·52	137	580·36	115
March	580·09	163	579·45	160	580·61	150	580·47	163
April	580·36	180	579·72	176	580·88	150	580·69	178
May	580·45	185	579·81	182	581·16	150	580·87	183
June	580·63	188	579·99	184	581·45	171	580·97	184
July	580·81	191	580·17	188	581·77	190	581·10	191
August	580·71	192	580·07	188	581·80	198	581·17	192
September	580·79	193	580·15	190	581·73	230	581·23	195
October	580·62	196	579·98	192	581·58	227	581·28	196
November	580·26	192	579·62	189	581·32	223	581·10	193
December	579·94	159	579·30	155	580·98	185	580·79	158
1904—								
January	579·99	138	579·38	135	580·70	158	580·66	138
February	579·98	131	579·37	127	580·61	149	580·57	127
March	580·26	147	579·65	144	580·70	150	580·63	147
April	580·72	181	580·11	177	581·11	150	580·96	185
May	581·09	194	580·48	191	581·56	150	581·33	193
June	581·47	202	580·86	198	581·98	233	581·67	198
July	581·48	205	580·87	202	582·08	234	581·85	202
August	581·38	206	580·77	202	581·94	233	581·79	203
September	581·31	203	580·70	200	581·71	229	581·74	205
October	581·18	204	580·57	200	581·60	150	581·67	223
November	580·88	201	580·27	198	581·42	226	581·45	219
December	580·54	187	579·93	183	581·10	214	581·10	184

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharg (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (h)	Discharge (i)
1905—								
January	580·39	97	579·81	93	580·87	110	580·87	93
February	580·31	103	579·73	98	580·67	114	580·71	96
March	580·45	150	579·87	146	580·72	168	580·67	147
April	580·83	196	580·25	191	580·90	217	580·87	191
May	581·09	199	580·51	195	581·28	179	581·14	194
June	581·48	206	580·90	201	581·58	173	581·44	196
July	581·62	208	581·04	204	581·87	231	581·68	200
August	581·59	208	581·01	203	581·79	230	581·74	202
September	581·49	208	580·91	204	581·74	230	581·74	204
October	581·05	205	580·47	200	581·53	227	581·57	219
November	580·78	201	580·20	197	581·26	222	581·27	195
December	580·63	195	580·05	190	581·01	218	581·06	192
1906—								
January	580·61	184	580·03	180	580·83	163	580·97	181
February	580·76	141	580·18	136	580·89	156	581·01	136
March	580·91	164	580·33	160	580·93	176	581·13	158
April	581·09	191	580·51	186	580·98	196	581·24	187
May	581·35	206	580·77	202	581·13	172	581·40	199
June	581·47	207	580·89	202	581·37	190	581·55	199
July	581·48	208	580·90	204	581·57	155	581·64	202
August	581·45	206	580·87	201	581·63	159	581·64	201
September	581·10	202	580·52	198	581·47	166	581·52	200
October	580·91	197	580·33	192	581·23	164	581·29	195
November	580·75	194	580·17	190	581·08	150	581·13	193
December	580·70	170	580·12	165	581·06	161	581·06	167
1907—								
January	580·64	142	580·05	139	580·92	150	581·03	139
February	580·68	127	580·09	123	580·86	140	580·99	122
March	580·74	167	580·15	164	580·91	178	580·99	162
April	581·00	190	580·41	186	581·10	195	581·09	184
May	581·16	200	580·57	197	581·27	151	581·26	194
June	581·52	204	580·93	200	581·57	166	581·48	197
July	581·52	209	580·93	206	581·86	173	581·66	200
August	581·44	206	580·85	202	581·87	232	581·68	201
September	581·42	206	580·83	203	581·73	229	581·65	203
October	581·17	202	580·58	198	581·63	227	581·55	218
November	580·76	196	580·17	193	581·36	150	581·25	194
December	580·65	189	580·06	185	581·08	214	581·01	190
1908—								
January	580·48	122	579·90	120	580·86	139	580·91	119
February	580·57	114	579·99	111	580·69	126	580·80	108
March	580·64	108	580·06	106	580·68	119	580·81	103
April	580·94	186	580·36	183	580·86	150	580·99	182
May	581·50	198	580·92	196	581·32	181	581·36	194
June	581·64	205	581·06	202	581·66	226	581·69	199
July	581·83	209	581·25	207	581·91	232	581·85	205
August	581·72	206	581·14	203	581·97	233	581·88	204
September	581·28	201	580·70	199	581·60	156	581·67	201
October	580·92	194	580·34	191	581·24	154	581·31	194
November	580·27	189	579·69	187	580·87	170	580·91	189
December	580·13	187	579·55	184	580·57	197	580·59	184
1909—								
January	579·88	162	579·31	160	580·30	170	580·31	159

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (h)	Discharge (i)
1909—								
February	580·02	110	579·45	107	580·17	121	580·18	103
March	580·10	146	579·53	144	580·22	150	580·25	143
April	580·36	182	579·79	179	580·33	150	580·39	180
May	580·88	187	580·31	185	580·78	150	580·76	185
June	581·08	195	580·51	192	581·23	150	581·17	189
July	581·05	196	580·48	194	581·42	150	581·27	191
August	581·07	194	580·50	191	581·45	153	581·23	192
September	580·80	192	580·23	190	581·36	179	581·08	191
October	580·32	187	579·75	184	581·07	183	580·79	185
November	580·21	183	579·64	181	580·80	158	580·52	184
December	580·17	172	579·60	169	580·77	196	580·45	180
1910—								
January	579·95	126	579·50	125	580·62	143	580·31	118
February	579·94	135	579·49	133	580·50	150	580·19	125
March	580·01	181	579·56	180	580·52	150	580·19	172
April	580·37	185	579·92	183	580·70	150	580·33	176
May	580·50	189	580·05	188	589·97	150	580·54	180
June	580·57	192	580·12	190	581·17	150	580·70	181
July	580·49	189	580·04	188	581·23	150	580·68	182
August	580·33	189	579·88	187	581·15	150	580·54	181
September	580·29	187	579·84	186	581·08	150	580·47	182
October	580·10	186	579·65	184	580·98	190	580·37	178
November	579·78	183	579·33	182	580·71	160	580·18	175
December	579·46	153	579·01	151	580·41	162	579·85	145
1911—								
January	579·20	126	578·85	125	580·12	146	579·59	113
February	579·40	124	579·05	122	580·03	141	579·55	116
March	579·23	171	578·88	170	579·98	150	579·54	164
April	579·50	173	579·15	171	580·05	150	579·59	168
May	579·77	180	579·42	179	580·33	150	579·81	172
June	580·05	185	579·70	183	580·65	150	580·11	174
July	579·89	184	579·54	183	580·82	184	580·21	177
Aug.	579·85	183	579·50	181	580·74	168	580·14	174
September	579·75	178	579·40	177	580·78	188	580·08	175
October	579·65	177	579·30	175	580·75	157	580·00	172
November	579·37	176	579·02	175	580·67	171	579·95	173
December	579·48	170	579·13	168	580·57	150	579·91	167
1912—								
January	579·27	126	578·94	125	580·55	150	579·87	120
February	579·29	129	578·96	127	580·40	150	579·78	124
March	579·35	145	579·02	144	580·39	150	579·76	139
April	579·52	170	579·19	168	580·48	150	579·88	169
May	580·05	184	579·72	183	580·85	150	580·21	175
June	580·46	188	580·13	186	581·38	189	580·71	183
July	580·53	188	580·20	187	581·62	165	580·94	188
August	580·63	190	580·30	188	581·72	175	580·99	191
September	580·71	194	480·38	193	581·81	230	581·18	194
October	580·41	192	580·08	190	581·64	228	581·20	194
November	580·42	194	580·09	193	581·40	222	581·14	194
December	580·18	193	579·85	191	581·20	222	581·09	191
1913—								
January	580·01	175	579·69	175	580·95	150	580·94	176

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharg (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (h)	Discharge (i)
1913—								
February	579·84	129	579·52	128	580·89	150	580·78	127
March	580·13	158	579·81	158	580·84	150	580·76	159
April	580·82	179	580·50	178	581·28	150	581·16	183
May	581·13	187	580·81	187	581·82	150	581·61	193
June	581·26	190	580·94	189	582·07	234	581·78	197
July	581·26	198	580·94	198	582·20	236	581·63	201
August	581·26	200	580·94	199	582·08	236	581·81	202
September	580,98	195	580·66	195	581·92	234	581·71	202
October	580·75	191	580·43	190	581·61	228	581·51	219
November	580·44	190	580·12	190	581·41	224	581·29	194
December	580·30	184	579·98	183	581·24	218	581·14	192
1914—								
January	580·07	146	579·77	146	580·96	171	580·99	150
February	580·04	137	579·74	136	580·82	158	580·81	137
March	579·99	151	579·69	151	580·78	162	580·73	151
April	580·15	174	579·85	173	580·73	150	580·70	183
May	580·36	180	580·06	180	580·91	150	580·81	184
June	580·64	182	580·34	181	581·21	150	581·03	185
July	580·79	189	580·49	189	581·50	150	581·18	190
August	580·69	190	580·39	189	581·56	171	581·16	191
September	580·49	192	580·19	192	581·43	162	581·05	192
October	580·37	188	580·07	187	581·30	168	580·93	189
November	579·82	183	579·52	183	581·00	178	580·67	185
December	579·53	162	579·23	161	580·70	150	580·35	161
1915—								
January	579·45	117	579·17	117	580·50	138	580·10	113
February	579·67	134	579·39	133	580·40	150	580·06	132
March	579·60	146	579·32	146	580·48	150	580·10	142
April	579·56	167	579·28	166	580·43	150	580·05	163
May	579·73	171	579·45	171	580·45	150	580·04	174
June	579·89	175	579·61	174	580·59	150	580·15	174
July	579·98	182	579·70	182	580·80	150	580·24	176
August	580·21	184	579·93	183	580·97	150	580·37	177
September	580·01	181	579·73	181	581·15	150	580,41	180
October	579·81	180	579·53	179	581·01	157	580·32	177
November	579·46	176	579·18	176	580·95	186	580·16	176
December	579·41	164	579·13	163	580·85	202	580·04	163
1916—								
January	579·16	153	578·90	153	580·72	150	579·98	152
February	579·30	124	579·04	123	580·79	150	580·00	120
March	579·46	122	579·20	122	580·93	150	580·13	122
April	579·95	150	579·69	149	581·06	156	580·35	150
May	580·49	184	580·23	184	581·56	200	580·80	188
June	581·10	193	580·84	192	582·11	234	581·42	196
July	581·31	197	581·05	197	582·47	215	581·85	204
August	581·06	201	580·80	200	582·41	243	581·94	204
September	580·67	198	580·41	198	582·07	237	581·76	223
October	580·50	196	580·24	195	581·75	231	581·45	199
November	580·65	193	580·39	193	581·68	231	581·38	220
December	580·56	186	580·30	185	581·55	218	581·34	186
1917—								
January	580·44	144	580·22	145	581·26	165	581·23	142
February	580·36	145	580·14	145	581·20	166	581·13	143

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharg (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (h)	Discharge (i)
1917—								
March	580·49	191	580·27	192	581·09	220	581·10	195
April	580·85	185	580·63	185	581·28	222	581·22	184
May	581·18	193	580·96	194	581·55	190	581·48	196
June	581·63	201	581·41	201	581·83	230	581·78	199
July	581·97	211	581·75	212	582·09	208	582·10	206
August	581·91	212	581·69	212	582·20	239	582·29	230
September	581·71	206	581·49	207	581·97	234	582·19	229
October	581·39	203	581·17	203	581·57	228	581·93	223
November	581·20	195	580·98	196	581·27	184	581·71	220
December	580·77	150	580·55	150	581·00	168	581·44	149
1918—								
January	580·82	125	580·60	126	580·85	136	581·23	122
February	580·84	143	580·62	143	580·77	156	581·24	140
March	581·13	168	580·91	169	580·92	181	581·37	166
April	581·50	131	581·28	131	581·15	139	581·64	125
May	581·75	199	581·53	200	581·41	210	581·94	197
June	581·98	208	581·76	208	581·63	218	582·20	213
July	581·97	212	581·75	213	581·70	155	582·29	235
August	581·87	212	581·65	212	581·75	158	582·15	229
September	581·49	210	581·27	211	581·62	174	581·94	227
October	581·20	202	580·98	202	581·43	201	581·64	220
November	581·07	200	580·85	201	581·25	222	581·47	220
December	581·13	196	580·91	196	581·23	227	581·44	197
1919—								
January	580·77	189	580·56	190	581·05	204	581·35	181
February	580·71	178	580·50	178	580·91	163	581·18	172
March	580·81	181	580·60	182	581·06	181	581·12	177
April	581·14	187	580·93	187	581·16	205	581·33	182
May	581·46	195	581·25	196	581·48	194	581·66	191
June	581·60	198	581·39	198	581·68	150	581·89	200
July	581·37	203	581·16	204	581·86	218	581·86	201
August	581·12	199	580·91	199	581·66	152	581·70	199
September	580·77	197	580·56	198	581·49	150	581·50	198
October	580·68	193	580·47	193	581·33	173	581·29	195
November	580·42	189	580·21	190	581·17	221	581·09	192
December	580·08	154	579·87	154	580·85	173	580·84	148
1920—								
January	580·00	108	579·79	108	580·62	118	580·65	99
February	580·04	119	579·83	118	580·51	131	580·57	113
March	580·19	155	579·98	155	580·58	170	580·59	152
April	580·57	189	580·36	188	580·92	217	580·86	194
May	580·82	186	580·61	186	581·31	194	581·17	195
June	580·93	192	580·72	191	581·40	150	581·26	194
July	581·08	200	580·87	200	581·62	188	581·35	196
August	581·11	201	580·90	200	581·73	184	581·45	198
September	580·93	201	580·72	201	581·57	158	581·39	197
October	580·59	190	580·38	189	581·37	172	581·22	194
Nov	580·32	182	580·11	182	581·11	152	581·02	190
December	580·10	184	579·89	183	580·91	163	580·79	180
1921—								
January	579·91	181	579·71	181	580·76	177	580·61	178
February	579·87	126	579·67	125	580·64	144	580·44	119
March	579·96	162	579·76	162	580·53	166	580·43	160

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (h)	Discharge (i)
1921—								
April	580·44	183	580·24	182	580·78	165	580·68	181
May	580·62	180	580·42	180	581·19	150	581·01	186
June	580·65	186	580·45	185	581·37	150	581·13	187
July	580·48	191	580·28	191	581·42	150	581·08	188
August	580·18	189	579·98	188	581·35	150	580·90	185
September	580·03	189	579·83	189	581·31	180	580·71	186
October	579·87	185	579·67	184	581·16	199	580·60	183
November	579·69	175	579·49	175	580·90	150	580·38	179
December	579·51	170	579·31	169	580·77	150	580·21	166
1922—								
January	579·29	127	579·10	128	580·68	153	580·07	127
February	579·26	126	579·07	126	580·41	148	579·94	126
March	579·50	165	579·31	166	580·44	172	580·00	164
April	580·04	176	579·85	176	580·85	191	580·39	174
May	580·52	183	580·33	184	581·37	213	580·89	186
June	580·62	190	580·43	190	581·63	217	581·22	192
July	580·73	196	580·54	197	581·73	161	581·36	195
August	580·64	196	580·45	196	581·82	180	581·40	195
September	580·43	193	580·24	194	581·72	228	581·27	194
October	580·02	186	579·83	186	581·35	159	580·97	188
November	579·59	180	579·40	181	581·03	166	580·59	182
December	579·14	181	578·95	181	580·80	170	580·19	176
1923—								
January	579·10	141	578·91	141	580·41	170	579·93	140
February	578·83	116	578·64	115	580·17	135	579·76	112
March	579·04	165	578·85	165	580·15	150	579·74	164
April	579·27	167	579·08	166	580·33	150	579·93	165
May	579·70	183	579·51	183	580·70	150	580·25	180
June	579·90	188	579·71	187	581·07	150	580·57	183
July	579·96	186	579·77	186	851·28	196	580·71	185
August	579·79	185	579·60	184	581·20	171	580·66	184
September	579·69	184	579·50	184	581·09	183	580·52	183
October	579·41	181	579·22	180	580·92	176	580·35	179
November	579·09	176	578·90	176	580·65	164	580·07	174
December	578·80	170	578·61	160	580·37	150	579·79	169
1924—								
January	578·54	146	578·40	148	580·19	150	579·55	145
February	578·77	120	578·63	121	580·13	143	579·51	116
March	578·75	145	578·61	147	580·14	150	579·56	143
April	578·99	160	578·85	161	580·23	150	579·67	159
May	579·29	173	579·15	175	580·53	150	579·94	170
June	579·45	176	579·31	177	580·82	150	580·20	171
July	579·53	177	579·39	179	581·03	150	580·34	177
August	579·67	181	579·53	182	581·23	150	580·50	179
September	579·55	182	579·41	184	581·28	150	580·51	181
October	579·30	174	579·16	175	581·17	150	580·30	175
November	578·78	169	578·64	171	580·82	150	589·91	170
December	578·47	146	578·33	147	580·45	150	579·51	144
1925—								
January	578·30	127	578·26	128	580·19	150	579·25	126
February	578·25	432	578·21	132	589·99	150	579·11	131
March	578·33	149	578·29	150	580·02	150	579·13	150
April	578·51	160	578·47	160	580·09	150	579·22	161

TABLE 10.—EFFECT OF REGULATION—LAKE MICHIGAN-HURON—*Concluded*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Montnly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (h)	Discharge (i)
1925—								
May	578·45	163	578·41	164	580·17	150	579·27	162
June	578·50	163	578·46	163	580·21	150	579·29	162
July	578·59	164	578·55	165	580·30	150	579·35	163
August	578·52	161	578·48	161	580·30	150	579·34	161
September	578·32	158	578·28	159	580·16	150	579·17	158
October	577·92	156	577·88	156	579·91	150	578·89	153
November	577·68	151	577·64	152	579·64	150	578·61	151
December	577·47	155	577·43	155	579·42	150	578·40	138

TABLE 11—EFFECT OF REGULATION—LAKE ERIE

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharg (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (h)	Discharge (i)
1860—								
January	573·26	224	572·44	217	....	....	572·50	197
February	572·90	216	572·08	208	....	....	572·20	184
March	573·30	225	572·48	218	....	....	572·35	190
April	574·00	241	573·18	233	....	....	573·05	219
May	574·21	246	573·39	239	....	....	573·54	235
June	574·18	245	573·36	237	....	....	573·57	237
July	573·92	239	573·10	232	....	....	573·29	240
August	573·76	236	572·94	228	....	....	573·00	231
September	573·42	228	572·60	221	....	....	572·72	222
October	573·12	221	572·30	213	....	....	572·37	205
November	573·03	219	572·21	212	....	....	572·35	203
December	572·87	216	572·05	208	....	....	572·31	226
1861—								
January	572·61	210	571·79	203	....	....	571·88	176
February	572·33	204	571·51	196	....	....	571·82	176
March	572·77	213	572·01	206	....	....	572·02	177

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (h)	Discharge (i)
1861—								
April	573·81	237	572·99	229	....	....	572·90	212
May	574·24	247	573·42	240	....	....	573·70	241
June	574·31	248	573·49	240	....	....	573·84	245
July	574·06	243	573·24	236	....	....	573·60	248
August	574·10	244	573·28	236	....	....	573·49	259
September	573·92	239	573·10	232	....	....	573·29	242
October	573·69	234	572·87	226	....	....	573·11	234
November	573·67	234	572·85	227	....	....	573·00	248
December	573·44	228	572·62	220	....	....	572·77	245
1862—								
January	573·43	228	572·61	221	....	....	572·54	198
February	573·14	222	572·32	214	....	....	572·54	198
March	573·28	225	572·46	218	....	....	572·54	198
April	574·18	245	573·36	237	....	....	573·11	221
May	574·42	251	573·60	244	....	....	573·77	243
June	547·42	251	573·60	243	....	....	573·81	244
July	574·39	250	573·57	243	....	....	573·71	252
August	574·01	241	573·19	233	....	....	573·60	262
September	573·70	234	572·88	227	....	....	573·15	235
October	573·32	226	572·50	218	....	....	572·86	227
November	572·98	218	572·16	211	....	....	572·53	218
December	573·01	219	572·19	211	....	....	572·43	237
1863—								
January	573·46	229	572·64	222	....	....	572·56	199
February	573·75	235	572·93	227	....	....	573·07	219
March	573·69	234	572·87	227	....	....	573·18	225
April	573·81	237	572·99	229	....	....	573·17	224
May	573·99	241	573·17	234	....	....	573·31	229
June	573·85	238	573·03	230	....	....	573·29	228
July	573·73	235	572·91	228	....	....	573·07	233
August	573·65	233	572·83	225	....	....	572·83	226
September	573·26	224	572·44	217	....	....	572·53	217
October	572·82	214	572·00	206	....	....	572·04	178
November	572·41	205	571·61	198	....	....	571·79	176
December	572·38	205	571·56	197	....	....	571·73	176
1864—								
January	572·09	198	571·27	191	....	....	571·68	176
February	572·24	202	571·42	194	....	....	571·69	176
March	572·45	206	571·63	199	....	....	571·96	176
April	572·95	217	572·13	209	....	....	572·41	192
May	573·65	233	572·83	226	....	....	573·14	222
June	573·60	232	572·78	224	....	....	573·40	231
July	573·34	226	572·52	219	....	....	573·14	235
August	573·07	220	572·25	212	....	....	572·64	220
September	572·85	215	572·03	208	....	....	572·27	198
October	572·54	208	571·72	200	....	....	572·05	178
November	572·37	205	571·55	198	....	....	571·97	176
December	572·44	206	571·62	198	....	....	572·06	195
1865—								
January	572·01	197	571·19	190	....	....	571·90	176
February	571·43	184	570·61	176	....	....	571·55	176
March	571·75	191	570·93	184	....	....	571·32	176
April	572·47	207	571·65	199	....	....	571·86	176

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1865—								
May	573·05	220	572·23	213	....	....	572·65	202
June	573·03	219	572·21	211	....	....	572·99	216
July	572·99	218	572·17	211	....	....	572·89	228
August	572·91	216	572·09	208	....	....	572·62	219
September	572·87	216	572·05	209	....	....	572·43	210
October	572·57	209	571·75	201	....	....	572·23	194
November	572·19	201	571·37	194	....	....	571·93	176
December	572·05	198	571·23	190	....	....	571·83	176
1866—								
January	571·78	192	570·96	185	....	....	571·77	176
February	571·62	188	570·80	180	....	....	571·65	176
March	572·01	197	571·19	190	....	....	571·81	176
April	572·59	209	571·77	201	....	....	572·39	192
May	572·81	214	571·99	207	....	....	572·84	210
June	573·07	220	572·25	212	....	....	573·02	217
July	573·18	222	572·36	215	....	....	573·14	235
August	572·93	217	572·11	209	....	....	572·86	227
September	572·87	216	572·05	209	....	....	572·51	216
October	572·86	215	572·04	207	....	....	572·40	207
November	572·62	210	571·80	203	....	....	572·31	200
December	572·63	210	571·81	202	....	....	572·22	214
1867—								
January	572·34	204	571·52	197	....	....	572·07	179
February	572·02	197	571·20	189	....	....	571·90	176
March	572·42	200	571·60	199	....	....	572·03	178
April	572·74	213	571·92	105	....	....	572·54	198
May	573·26	224	572·44	217	....	....	573·02	218
June	573·57	231	572·75	223	....	....	573·43	233
July	573·38	227	572·56	220	....	....	573·40	243
August	573·07	220	572·25	212	....	....	572·90	228
September	572·68	211	571·86	204	....	....	572·44	211
October	572·34	204	571·52	196	....	....	572·01	177
November	571·84	193	571·02	186	....	....	571·78	176
December	571·62	188	570·80	180	....	....	571·52	176
1868—								
January	571·42	184	570·60	177	....	....	571·39	176
February	571·04	176	570·22	168	....	....	571·13	176
March	571·63	188	570·81	181	....	....	571·17	176
April	572·46	206	571·64	198	....	....	571·87	176
May	572·91	216	572·09	209	....	....	572·74	206
June	573·30	225	572·48	217	....	....	573·18	225
July	573·27	224	572·45	217	....	....	573·28	240
August	572·75	213	571·93	205	....	....	572·78	225
September	572·48	207	571·66	200	....	....	572·22	193
October	572·03	197	571·21	189	....	....	571·91	176
November	571·87	194	571·05	187	....	....	571·72	176
December	571·66	189	570·84	181	....	....	571·58	176
1869—								
January	571·65	189	570·83	182	572·20	180	571·54	176
February	571·58	187	570·76	179	572·06	198	571·50	176
March	572·06	198	571·24	191	572·43	199	571·75	176
April	572·36	204	571·54	196	572·67	194	572·35	190
May	572·91	216	572·09	209	572·56	176	572·81	210

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1869—								
June	573·30	225	572·48	217	573·55	231	573·22	226
July	573·58	232	572·76	225	573·67	279	573·42	243
August	573·48	229	572·66	221	573·63	246	573·33	245
September	573·21	223	572·39	216	573·47	245	572·87	227
October	572·76	213	571·94	205	573·23	222	572·33	202
November	572·30	203	571·48	196	572·73	210	571·89	176
December	572·65	211	571·83	203	572·77	218	571·98	186
1870—								
January	572·89	216	572·07	209	572·79	184	572·42	193
February	573·12	221	572·30	213	573·07	190	572·86	210
March	572·89	216	572·07	209	573·09	218	572·80	208
April	573·54	231	572·72	223	573·45	231	572·94	214
May	573·75	235	572·93	228	574·13	209	573·41	232
June	573·72	235	572·90	227	574·20	225	573·46	233
July	573·76	236	572·94	229	574·13	289	573·37	242
August	573·71	235	572·89	227	573·95	242	573·23	238
September	573·46	229	572·64	222	573·57	282	572·99	230
October	573·08	220	572·26	212	573·04	256	572·56	217
November	572·78	214	571·96	207	572·61	237	572·15	188
December	572·66	211	571·84	203	572·45	248	572·10	200
1871—								
January	572·45	206	571·63	199	572·20	201	572·03	177
February	572·12	199	571·30	191	571·98	176	571·88	176
March	572·57	209	571·75	202	572·38	229	572·03	177
April	573·05	220	572·23	212	572·77	222	572·67	203
May	573·32	226	572·50	219	573·22	239	573·08	220
June	573·35	226	572·53	218	573·41	230	573·15	222
July	573·33	226	572·51	219	573·54	248	573·06	232
August	573·12	221	572·30	213	573·43	249	572·76	224
September	572·95	217	572·13	210	573·15	176	572·43	210
October	572·28	203	571·46	195	572·65	176	571·98	176
November	572·10	199	571·28	192	572·11	176	571·75	176
December	571·66	189	570·84	181	571·69	176	571·56	176
1872—								
January	571·58	187	570·76	180	571·60	176	571·43	176
February	571·34	182	570·52	174	571·25	198	571·27	176
March	571·25	180	570·43	173	571·15	182	571·05	176
April	571·45	185	570·63	177	571·20	176	571·04	176
May	571·89	194	571·07	187	571·50	176	571·35	176
June	572·26	202	571·44	194	571·95	176	571·82	176
July	572·25	202	571·43	195	572·01	176	572·11	185
August	572·22	201	571·40	193	572·02	176	572·10	184
September	571·99	196	571·17	189	571·98	176	571·98	176
October	571·82	193	571·00	185	572·00	176	571·83	176
November	571·49	186	570·67	179	571·90	176	571·64	176
December	571·26	181	570·44	173	571·53	176	571·41	176
1873—								
January	571·16	179	570·34	172	571·27	176	571·23	176
February	571·17	179	570·35	171	571·10	176	571·09	176
March	571·24	180	570·42	173	571·43	176	571·07	176
April	572·52	208	571·70	200	572·20	176	571·74	176
May	573·19	223	572·37	216	573·25	229	572·95	215
June	573·27	225	572·45	217	573·15	231	573·31	229

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1873—								
July	573·25	224	572·43	217	573·30	225	573·18	237
Aug.	573·19	223	572·37	215	573·50	262	572·93	229
September	572·79	214	571·97	207	573·11	237	572·55	217
October	572·49	207	571·67	199	572·77	225	572·11	185
November	572·29	203	571·47	196	572·55	244	571·98	176
December	572·66	211	571·84	203	572·49	232	572·25	218
1874—								
January	573·05	220	572·23	213	572·50	198	572·50	197
February	573·10	221	572·28	213	573·08	202	572·91	213
March	573·13	221	572·31	214	573·39	218	572·91	213
April	573·30	225	572·48	217	573·10	204	572·99	216
May	573·39	227	572·57	220	573·46	180	573·10	221
June	573·46	229	572·64	221	573·52	184	573·21	226
July	573·49	230	572·67	223	573·57	256	573·16	235
August	573·33	226	572·51	218	573·47	256	572·94	229
September	572·87	216	572·05	209	573·05	223	572·50	216
October	572·43	206	571·61	198	572·67	200	571·92	176
November	572·01	197	571·19	190	572·46	201	571·66	176
December	571·80	192	570·98	184	572·25	183	571·48	176
1875—								
January	571·57	187	570·75	180	572·20	207	571·31	176
February	571·40	184	570·58	176	571·95	198	571·11	176
March	571·54	187	570·72	180	571·71	201	571·08	176
April	571·94	195	571·12	187	572·15	176	571·36	176
May	572·41	205	571·59	198	572·65	176	571·97	176
June	572·84	215	572·02	207	573·37	176	572·60	200
July	572·97	218	572·15	211	573·45	191	572·92	228
August	572·96	218	572·14	210	573·35	224	572·77	225
September	572·82	214	572·00	207	573·15	248	572·53	217
October	572·33	204	571·51	196	572·65	205	572·26	197
November	572·18	200	571·36	193	572·45	219	572·08	179
December	572·40	205	571·58	197	572·45	252	572·36	232
1876—								
January	572·36	204	571·54	197	572·24	248	572·12	180
February	572·92	217	572·10	209	572·36	176	572·51	197
March	573·57	232	572·75	225	573·10	209	573·22	226
April	574·09	243	573·27	235	573·40	232	573·87	246
May	574·41	251	573·59	244	573·62	245	574·20	256
June	574·52	253	573·70	245	574 04	272	574·30	259
July	574·41	251	573·59	244	574·04	268	574·17	266
August	574·11	244	573·29	236	573·56	258	573·91	269
September	573·94	240	573·12	233	573·68	278	573·58	261
October	573·41	228	572·59	220	573·12	265	573·12	234
November	573·49	230	572·67	223	572·72	243	572·93	247
December	573·15	222	572·33	214	572·60	266	572·72	243
1877—								
January	572·75	213	571·93	206	572·06	....	572·34	190
February	572·59	209	571·77	201	....	....	572·24	186
March	572·36	204	571·54	197	....	....	572·16	183
April	572·79	214	571·97	206	....	....	572·41	192
May	573·04	219	572·22	212	....	....	572·85	211
June	573·12	221	572·30	213	....	....	572·99	217
July	573·36	226	572·54	219	....	....	573·02	231

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c. .s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1877—								
August	573·22	223	572·40	215	....	....	572·83	226
September	573·14	222	572·32	215	....	....	572·50	216
October	572·74	213	571·92	205	....	....	572·35	203
November	572·66	211	571·84	204	....	....	572·25	197
December	572·74	213	571·92	205	....	....	572·44	237
1878—								
January	572·82	214	572·00	207	....	....	572·35	190
February	572·96	218	572·14	210	....	....	572·54	198
March	573·09	220	572·27	213	....	....	572·74	206
April	573·51	230	572·69	222	....	....	573·02	218
May	573·77	236	572·95	229	....	....	573·39	230
June	573·77	236	572·95	228	....	....	573·45	233
July	573·77	236	572·95	229	....	....	573·31	240
August	573·53	231	571·71	223	....	....	573·02	231
September	573·40	227	572·58	220	....	....	572·68	221
October	573·05	220	572·23	212	....	....	572·38	206
November	572·85	215	572·03	208	....	....	572·28	199
December	572·93	217	572·11	209	....	....	572·40	235
1879—								
January	572·51	208	571·69	201	....	....	572·04	177
February	572·37	205	571·55	197	....	....	571·93	176
March	572·40	205	571·58	198	....	....	572·02	177
April	572·76	213	571·94	205	....	....	572·37	191
May	572·91	216	572·09	209	....	....	572·74	206
June	573·00	218	572·18	210	....	....	572·88	212
July	573·03	219	572·21	212	....	....	572·87	227
August	572·81	214	571·99	206	....	....	572·58	218
September	572·48	207	571·66	200	....	....	572·15	187
October	572·25	202	571·43	194	....	....	571·93	176
November	571·78	192	570·96	185	....	....	571·72	176
December	572·04	197	571·22	189	....	....	571·63	176
1880—								
January	572·54	208	571·72	201	....	....	572·15	183
February	572·58	209	571·76	201	....	....	572·60	200
March	572·72	212	571·90	205	....	....	572·61	201
April	572·88	216	572·06	208	....	....	572·74	206
May	573·15	222	572·33	215	....	....	572·96	215
June	573·26	224	572·44	216	....	....	573·11	221
July	573·35	226	572·53	219	....	....	573·10	233
August	573·11	221	572·29	213	....	....	572·86	227
September	572·88	216	572·06	209	....	....	572·50	216
October	572·44	206	571·62	198	....	....	572·07	181
November	572·36	204	571·54	197	....	....	571·97	176
December	572·02	197	571·20	189	....	....	571·91	177
1881—								
January	571·61	188	570·79	182	....	....	571·73	176
February	571·72	190	570·90	183	....	....	571·61	176
March	572·04	197	571·22	191	....	....	571·85	176
April	572·74	213	571·92	206	....	....	572·47	195
May	573·14	222	572·32	216	....	....	573·09	220
June	573·38	227	572·56	220	....	....	573·34	230
July	573·33	226	572·51	220	....	....	573·32	240

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1881—								
August	573·01	219	572·19	212	....	....	572·90	228
September	572·66	211	571·84	205	....	....	572·44	211
October	572·61	210	571·79	203	....	....	572·21	214
November	572·43	206	571·61	200	....	....	572·33	202
December	572·64	210	571·82	203	....	....	572·43	237
1882—								
January	573·11	221	572·30	215	....	....	572·63	202
February	573·11	221	572·30	214	....	....	572·98	216
March	573·56	231	572·75	225	....	....	573·18	225
April	573·78	236	572·97	229	....	....	573·53	235
May	573·98	241	573·17	235	....	....	573·70	241
June	574·13	244	573·32	237	....	....	573·87	246
July	574·06	243	573·25	237	....	....	573·81	255
August	573·92	239	573·11	232	....	....	573·58	262
September	573·65	233	572·84	227	....	....	573·34	245
October	573·20	223	572·39	216	....	....	572·99	230
November	572·88	216	572·07	210	....	....	572·64	226
December	572·37	205	571·56	198	....	....	572·22	214
1883—								
January	572·28	202	571·48	196	....	....	571·99	176
February	572·49	207	571·69	200	....	....	572·22	185
March	572·68	211	571·88	205	....	....	572·51	198
April	572·80	214	572·00	207	....	....	572·72	205
May	573·26	224	572·46	218	....	....	573·02	218
June	573·96	240	573·16	233	....	....	573·53	237
July	574·16	245	573·36	239	....	....	573·93	259
August	574·10	244	573·30	237	....	....	574·01	271
September	573·79	236	572·99	230	....	....	573·65	264
October	573·47	229	572·67	222	....	....	573·18	237
November	573·09	220	572·29	214	....	....	572·84	242
December	573·12	221	572·32	214	....	....	572·45	237
1884—								
January	572·79	214	572·00	208	....	....	572·21	185
February	573·05	220	572·26	213	....	....	572·33	190
March	573·24	224	572·45	218	....	....	572·71	205
April	573·79	236	573·00	229	....	....	573·17	225
May	574·06	243	573·27	237	....	....	573·55	237
June	574·14	244	573·35	237	....	....	573·65	239
July	573·92	239	573·13	233	....	....	573·50	246
August	573·76	236	572·97	229	....	....	573·30	243
September	573·33	226	572·54	220	....	....	572·95	229
October	573·00	218	572·21	211	....	....	572·58	218
November	572·52	208	571·73	202	....	....	572·15	188
December	572·45	206	571·66	199	....	....	572·06	195
1885—								
January	572·27	202	571·49	196	....	....	571·92	176
February	572·06	198	571·28	191	....	....	571·86	176
March	571·92	195	571·14	189	....	....	571·77	176
April	572·74	213	571·96	206	....	....	572·24	186
May	573·47	229	572·69	223	....	....	573·18	225
June	573·98	241	573·20	234	....	....	573·66	240
July	573·94	240	573·16	234	....	....	573·72	253
August	573·95	240	573·17	233	....	....	573·61	262

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1885—								
September......	573·80	237	573·02	231	....	....	573·37	248
October.........	573·70	234	572·92	227	....	....	573·18	225
November......	573·58	232	572·80	226	....	....	573·19	253
December.......	573·53	231	572·75	224	....	....	572·95	248
1886—								
January.........	573·55	231	572·78	225	....	....	572·86	212
February........	572·82	214	572·05	207	....	....	572·59	200
March..........	572·63	210	571·86	204	....	....	572·14	181
April............	573·51	230	572·74	223	....	....	572·65	202
May............	573·81	237	573·04	231	....	....	573·40	232
June............	573·91	239	573·14	232	....	....	573·49	234
July............	573·89	239	573·12	233	....	....	573·37	242
August..........	573·68	234	572·91	227	....	....	573·23	238
September......	573·44	228	572·67	222	....	....	572·97	230
October.........	573·21	223	572·44	216	....	....	572·71	222
November......	572·80	214	572·03	208	....	....	572·38	206
December.......	572·85	215	572·08	208	....	....	572·25	218
1887—								
January.........	572·62	210	571·86	204	....	....	572·17	183
February........	573·04	219	572·28	212	....	....	572·38	192
March..........	573·85	236	573·09	230	....	....	573·06	219
April............	573·87	235	573·11	228	....	....	573·50	234
May............	574·05	240	573·29	234	....	....	573·46	233
June............	574·08	243	573·32	236	....	....	573·51	235
July............	573·84	239	573·08	233	....	....	573·33	241
August..........	573·52	230	572·76	223	....	....	572·84	226
September......	573·29	223	572·53	217	....	....	572·63	220
October.........	572·70	224	571·94	217	....	....	572·30	200
November......	572·43	212	571·67	206	....	....	571·92	176
December.......	572·45	216	571·69	209	....	....	571·98	186
1888—								
January.........	572·27	211	571·52	205	....	....	572·04	177
February........	572·00	198	571·25	191	....	....	572·01	177
March..........	572·10	199	571·35	193	....	....	572·00	176
April............	572·73	214	571·98	207	....	....	572·44	193
May............	572·98	217	572·23	211	....	....	572·93	214
June............	573·11	221	572·36	214	....	....	573·00	217
July............	573·26	226	572·51	220	....	....	572·97	230
August..........	573·16	223	572·41	216	....	....	572·83	226
September......	572·72	216	571·97	210	....	....	572·38	206
October.........	572·35	212	571·60	205	....	....	571·95	176
November......	572·41	208	571·66	202	....	....	572·22	193
December.......	572·29	215	571·54	208	....	....	572·40	235
1889—								
January.........	572·31	211	571·57	205	....	....	572·05	178
February........	572·15	206	571·41	199	....	....	572·22	185
March..........	571·99	198	571·25	192	....	....	572·16	183
April............	572·34	206	571·60	199	....	....	572·28	188
May............	572·52	209	571·78	203	....	....	572·63	202
June............	572·95	220	572·21	213	....	....	572·91	214
July............	573·15	221	572·41	215	....	....	573·15	235
August..........	572·84	219	572·10	212	....	....	572·84	226
September......	572·45	210	571·71	204	....	....	572·29	199

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1889—								
October	572·03	199	571·29	192	....	....	571·87	176
November	571·76	199	571·02	193	....	....	571·64	176
December	572·02	206	571·28	199	....	....	571·76	176
1890—								
January	572·38	219	571·65	213	....	....	572·29	188
February	572·67	215	571·94	208	....	....	572·82	210
March	572·79	220	572·06	214	....	....	572·97	216
April	573·28	226	572·55	219	....	....	573·25	227
May	573·62	234	572·89	228	....	....	573·56	237
June	573·99	242	573·26	235	....	....	573·78	244
July	573·61	235	572·88	229	....	....	573·65	251
August	573·17	225	572·44	218	....	....	573·01	231
September	572·98	217	572·25	211	....	....	572·53	217
October	572·79	216	572·06	209	....	....	572·25	195
November	572·76	221	572·03	215	....	....	572·28	198
December	572·53	215	571·80	208	....	....	572·28	222
1891—								
January	572·31	209	571·59	203	....	....	571·96	176
February	572·29	206	571·57	199	....	....	572·12	180
March	572·75	210	572·03	204	....	....	572·48	195
April	572·62	212	571·90	205	....	....	572·75	206
May	572·44	207	571·72	201	....	....	572·58	200
June	572·58	207	571·86	200	....	....	572·53	198
July	572·48	211	571·76	205	....	....	572·51	217
August	572·21	205	571·49	198	....	....	572·13	186
September	572·03	201	571·31	195	....	....	571·95	176
October	571·65	193	570·93	186	....	....	571·76	176
November	571·21	191	570·49	185	....	....	571·39	176
December	571·28	192	570·56	185	....	....	571·23	176
1892—								
January	571·31	190	570·60	184	....	....	571·35	176
February	571·10	176	570·39	169	....	....	571·30	176
March	571·14	180	570·43	174	....	....	571·16	176
April	571·70	198	570·99	191	....	....	571·44	176
May	572·50	207	571·79	201	....	....	572·24	186
June	573·26	225	572·55	218	....	....	573·13	222
July	573·38	230	572·67	224	....	....	573·49	245
August	573·03	222	572·32	215	....	....	573·09	233
September	572·71	216	572·00	210	....	....	572·52	217
October	572·15	208	571·44	201	....	....	571·96	176
November	571·82	200	571·11	194	....	....	571·69	176
December	571·55	200	570·84	193	....	....	571·47	176
1893—								
January	571·17	183	570·47	177	....	....	571·37	176
February	571·25	182	570·55	175	....	....	571·16	176
March	571·47	188	570·77	182	....	....	571·23	176
April	572·20	203	571·50	196	....	....	571·76	176
May	573·04	219	572·34	213	....	....	572·71	205
June	573·23	226	572·53	219	....	....	573·21	225
July	572·95	224	572·25	218	....	....	573·03	232
August	572·61	210	571·91	203	....	....	572·51	217
September	572·23	205	571·53	199	....	....	571·98	176
October	571·88	203	571·18	196	....	....	571·81	176

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1893—								
November	571·48	202	570·78	196	....	....	571·60	176
December	571·56	202	570·86	195	....	....	571·60	176
1894—								
January	571·84	202	571·14	196	572·20	200	571·97	176
February	571·72	193	571·02	186	572·00	179	572·20	185
March	571·75	196	571·05	190	572·16	205	572·13	181
April	572·15	200	571·45	193	572·51	180	572·37	191
May	572·54	211	571·84	205	573·30	237	572·74	206
June	572·85	220	572·15	213	573·62	263	573·05	219
July	572·73	216	572·03	210	573·62	258	573·02	231
August	572·36	206	571·66	199	573·20	210	572·52	217
September	572·19	202	571·49	196	573·16	176	572·10	184
October	571·87	202	571·17	195	572·88	176	571·96	176
November	571·63	198	570·93	192	572·50	232	571·85	176
December	571·66	195	570·86	188	572·25	224	571·82	176
1895—								
January	571·23	192	570·53	186	572·05	212	571·75	176
February	571·00	177	570·30	170	571·91	178	571·65	176
March	571·01	176	570·31	170	571·72	182	571·58	176
April	571·26	180	570·56	173	571·82	176	571·68	176
May	571·48	187	570·78	181	571·92	176	571·87	176
June	571·57	190	570·87	183	571·94	176	572·05	177
July	571·46	190	570·76	184	571·97	176	572·05	177
August	571·38	186	570·68	179	572·00	176	571·95	176
September	571·28	186	570·58	180	571·93	180	571·84	176
October	570·80	182	570·10	175	571·66	176	571·64	176
November	570·70	171	570·00	165	571·42	217	571·29	176
December	570·86	176	570·16	169	571·30	176	571·20	176
1896—								
January	570·96	180	570·27	174	571·27	176	571·32	176
February	570·88	178	570·19	171	571·15	176	571·33	176
March	570·83	171	570·14	165	571·43	176	571·21	176
April	571·28	181	570·59	174	571·54	176	571·32	176
May	571·66	192	570·97	186	571·85	176	571·73	176
June	571·93	192	571·24	185	572·15	176	572·15	181
July	571·81	196	571·12	190	572·09	176	572·23	194
August	572·02	201	571·33	194	572·34	176	572·23	194
September	571·70	192	571·01	186	572·23	176	572·18	191
October	571·46	186	570·77	179	571·82	176	571·85	176
November	571·09	186	570·40	180	571·56	176	571·71	176
December	571·12	182	570·43	175	571·40	176	571·56	176
1897—								
January	571·09	190	570·40	184	571·43	176	571·59	176
February	571·29	180	570·60	173	571·52	218	571·78	176
March	571·66	191	570·97	185	571·68	176	572·12	180
April	572·21	203	571·52	196	572·07	176	572·66	203
May	572·54	212	571·85	206	572·55	176	573·02	217
June	572·64	212	571·95	205	572·83	185	573·10	221
July	572·63	211	571·94	205	573·05	183	572·96	230
August	572·47	208	571·78	201	573·17	176	572·60	219
September	572·19	201	571·50	195	573·02	176	572·19	191
October	571·70	191	571·01	184	572·58	187	571·83	176
November	571·57	192	570·88	186	572·21	182	571·61	176
December	571·54	194	570·85	187	572·10	176	571·61	176

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly Mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1898—								
January	571·59	192	570·91	186	572·00	179	571·75	176
February	571·79	189	571·11	182	571·98	177	572·00	176
March	572·05	198	571·37	192	572·33	188	572·30	188
April	572·63	211	571·95	204	572·61	218	572·78	208
May	572·78	214	572·10	208	573·17	185	573·08	220
June	572·81	214	572·13	207	573·29	176	573·07	220
July	572·59	210	571·91	204	573·15	176	572·84	226
August	572·39	209	571·71	202	573·16	176	572·40	207
September	572·01	200	571·33	194	572·95	176	572·05	177
October	571·81	197	571·13	190	572·59	176	571·88	176
November	571·69	199	571·01	193	572·56	185	571·85	176
December	571·52	200	570·84	193	572·22	176	571·83	176
1899—								
January	571·67	198	570·99	192	572·15	199	571·99	176
February	571·46	188	570·78	181	572·06	195	572·07	179
March	571·83	193	571·15	187	571·93	176	572·18	184
April	572·13	197	571·45	190	572·63	209	572·57	200
May	572·44	203	571·76	197	572·72	176	572·79	208
June	572·56	208	571·88	201	573·30	216	572·86	212
July	572·46	206	571·78	200	573·52	239	572·74	222
August	572·21	198	571·53	191	573·31	230	572·32	202
September	571·85	194	571·17	188	573·04	205	571·92	176
October	571·61	185	570·93	178	572·93	230	571·74	176
November	571·62	186	570·94	180	572·71	258	571·70	176
December	571·34	196	570·66	189	572·17	202	571·60	176
1900—								
January	571·36	189	570·69	186	572·25	191	571·59	176
February	571·57	188	570·90	184	572·52	216	571·80	176
March	571·92	192	571·25	189	572·82	226	572·02	177
April	572·23	200	571·56	196	573·00	231	572·49	195
May	572·39	204	571·72	201	572·75	176	572·72	205
June	572·47	205	571·80	201	572·86	176	572·80	208
July	572·34	206	571·67	203	572·76	176	572·68	221
August	572·31	203	571·64	199	572·58	176	572·39	207
September	571·99	198	571·32	195	572·80	176	572·15	188
October	571·75	190	571·08	186	572·76	222	571·93	176
November	571·49	193	570·82	190	572·52	233	571·79	176
December	571·45	192	570·78	188	572·27	221	571·76	176
1901—								
January	571·35	183	570·72	181	572·20	194	571·78	176
February	571·00	175	570·37	172	572·05	176	571·59	176
March	570·88	171	570·25	169	571·92	182	571·29	176
April	571·29	176	570·66	173	572·13	176	571·40	176
May	571·31	179	570·67	177	572·59	176	571·60	176
June	571·72	190	571·09	187	572·70	176	571·81	176
July	571·91	194	571·28	192	572·91	176	572·21	192
August	571·78	190	571·15	187	572·87	176	572·20	191
September	571·71	191	571·08	189	573·00	176	572·04	178
October	571·33	186	570·70	183	572·77	176	571·92	176
November	571·16	183	570·53	181	572·23	177	571·71	176
December	571·19	183	570·56	180	572·23	176	571·68	176
1902—								
January	571·08	184	570·50	182	572·26	178	571·69	176

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Discharges in Thousand Second Feet

Stages in Feet above Mean Sea Level

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1902—								
February	570·63	171	570·05	168	572·19	199	571·49	176
March	570·94	174	570·36	172	571·96	176	571·30	176
April	571·49	186	570·91	183	572·15	176	571·71	176
May	571·86	191	571·28	189	572·49	176	572·26	187
June	572·12	198	571·54	195	572·61	176	572·59	200
July	572·74	212	572·16	210	573·02	176	572·99	230
August	572·72	210	572·14	207	573·31	190	573·14	235
September	572·38	203	571·80	201	572·94	176	572·70	221
October	572·29	205	571·71	202	572·63	176	572·33	202
November	572·02	200	571·44	198	572·43	202	572·21	192
December	571·82	192	571·24	189	572·04	207	572·05	194
1903—								
January	571·72	196	571·18	195	572·10	176	571·89	176
February	571·70	190	571·16	188	572·44	209	572·04	177
March	572·28	200	571·74	199	572·76	217	572·39	192
April	573·05	215	572·51	213	573·13	208	573·15	222
May	573·09	215	572·55	214	573·41	204	573·48	234
June	573·05	217	572·51	215	573·20	176	573·29	228
July	572·98	218	572·44	217	573·39	195	573·11	234
August	572·76	210	572·22	208	573·45	225	572·80	225
September	572·59	208	572·05	207	573·20	254	572·48	214
October	572·25	204	571·71	202	572·87	244	572·18	190
November	571·77	197	571·23	196	572·42	219	571·91	176
December	571·43	197	570·89	195	572·10	176	571·70	176
1904—								
January	571·32	176	570·83	175	572·33	202	571·69	176
February	571·42	182	570·93	180	572·28	216	571·70	176
March	572·01	193	571·52	192	572·54	206	572·09	179
April	573·13	216	572·64	214	573·31	220	573·09	220
May	573·33	224	572·84	223	573·68	224	573·76	242
June	573·52	230	573·03	228	573·53	245	573·79	243
July	573·41	228	572·92	227	573·74	280	573·68	252
August	573·10	221	572·61	219	573·34	243	573·22	238
September	572·84	215	572·35	214	573·13	235	572·76	245
October	572·49	210	572·00	208	572·88	176	572·18	190
November	572·12	203	571·63	202	572·37	221	572·18	190
December	571·77	199	571·28	197	572·10	197	572·10	200
1905—								
January	571·52	191	571·07	189	572·08	179	571·79	176
February	571·31	180	570·86	177	572·12	232	571·73	176
March	571·18	182	570·73	180	571·58	185	571·50	176
April	571·83	192	571·38	189	571·98	189	571·80	176
May	572·46	205	572·01	203	572·86	176	572·56	199
June	572·98	218	572·53	215	573·53	220	573·16	224
July	573·06	225	572·61	223	573·54	271	573·34	241
August	572·87	220	572·42	217	573·30	241	573·07	233
September	572·63	215	572·18	213	573·12	240	572·69	221
October	572·31	211	571·86	208	572·88	239	572·31	201
November	571·93	203	571·48	201	572·46	227	572·29	199
December	571·91	206	571·46	203	572·24	221	572·07	197
1906—								
January	571·94	205	571·51	204	572·33	200	572·14	181
February	571·93	195	571·50	193	572·22	180	572·36	191

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1906—								
March	571·71	190	571·28	189	572·42	222	572·21	185
April	572·13	198	571·70	196	572·36	189	572·25	186
May	572·40	202	571·97	201	572·85	176	572·69	204
June	572·60	207	572·17	205	573·05	176	572·87	212
July	572·64	209	572·21	208	573·33	176	572·89	228
August	572·63	208	572·20	206	573·20	176	572·69	221
September	572·35	202	571·92	201	572·95	176	572·39	206
October	572·21	202	571·78	200	572·64	176	572·12	186
November	572·17	204	571·74	203	572·53	188	572·19	191
December	572·42	206	571·99	204	572·40	241	572·42	237
1907—								
January	572·76	218	572·34	218	572·33	208	572·44	193
February	572·46	207	572·04	206	572·60	217	572·70	200
March	572·24	201	571·82	201	572·37	215	572·43	193
April	572·71	210	572·29	207	572·50	185	572·62	201
May	572·88	215	572·46	215	573·14	176	573·00	217
June	573·27	222	572·85	221	573·35	176	573·23	226
July	573·31	226	572·89	226	573·62	208	573·36	242
August	573·03	219	572·61	218	573·38	247	573·03	232
September	572·77	214	572·35	214	573·12	234	572·61	219
October	572·69	214	572·27	213	573·02	260	572·38	206
November	572·41	212	571·99	212	572·67	203	572·44	211
December	572·26	210	571·84	209	572·17	234	572·23	216
1908—								
January	572·57	126	572·17	217	572·30	185	572·29	188
February	572·19	204	571·79	204	572·71	226	572·52	198
March	572·66	208	572·26	209	572·71	201	572·58	200
April	573·27	222	572·87	222	573·43	273	573·19	220
May	573·51	228	573·11	229	573·10	199	573·61	238
June	573·51	228	573·11	228	573·35	228	573·62	238
July	573·32	224	572·92	225	573·48	238	573·40	241
August	573·14	220	572·74	220	573·41	246	573·03	232
September	572·68	211	572·28	212	573·14	176	572·60	219
October	572·31	200	571·91	200	572·67	176	572·12	185
November	571·71	200	571·31	201	572·09	176	571·80	176
December	571·42	196	571·02	196	570·70	176	571·57	176
1909—								
January	571·48	186	571·14	187	501·89	217	571·63	176
February	571·46	187	571·12	187	571·72	176	571·74	176
March	571·78	191	571·44	192	572·13	218	571·93	176
April	572·08	197	571·74	197	572·25	176	572·35	185
May	572·90	215	572·56	216	572·77	176	573·03	218
June	573·20	220	572·86	220	573·36	195	573·56	237
July	573·00	220	572·66	221	573·27	176	573·42	243
August	572·80	211	572·46	211	573·08	176	572·97	230
September	572·36	203	572·02	204	572·75	176	572·47	213
October	571·76	198	571·42	198	572·37	176	572·16	189
November	571·61	189	571·27	190	572·18	176	571·87	176
December	571·39	198	571·05	198	571·79	179	571·83	176
1910—								
January	571·25	183	570·97	185	572·17	187	571·95	176
February	571·16	176	570·88	177	572·20	216	571·87	176
March	571·66	187	571·38	189	572·25	183	572·01	177

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1910—								
April	572·08	196	571·80	197	572·48	176	572·51	197
May	572·57	209	572·29	211	572·83	176	572·90	213
June	572·61	208	572·33	209	572·07	176	573·07	220
July	572·40	205	572·12	207	572·93	176	572·78	225
August	572·22	199	571·94	200	572·42	176	572·35	204
September	572·02	193	571.74	195	572·35	176	572·05	179
October	571·88	195	571·60	196	572·03	176	571·98	176
November	571·46	190	571·18	192	572·00	176	571·83	176
December	571·34	186	571·06	187	571·67	176	571·62	176
1911—								
January	571·04	180	570·79	183	571·67	176	571·47	176
February	571·09	173	570·84	175	571·82	195	571·37	176
March	571·08	176	570·83	179	571·80	179	571·30	176
April	571·61	182	571·36	·184	571·90	176	571·53	176
May	571·88	192	571·63	195	572·19	176	571·98	176
June	571·94	193	571·69	195	572·28	176	572·26	187
July	571·75	193	571·50	196	572·08	176	572·18	190
August	571·61	186	571·36	188	572·13	176	572·00	176
September	571·52	181	571·27	184	572·00	176	571·93	176
October	571·53	184	571·28	186	572·13	176	571·93	176
November	571·13	192	570·88	195	571·87	176	571·80	176
December	571·42	188	571·17	190	571·95	176	571·89	187
1912—								
January	571·28	186	571·06	189	571·99	189	571·98	176
February	571·08	174	570·86	176	572·05	199	571·91	176
March	571·23	174	571·01	177	572·05	178	571·88	176
April	572·28	198	572·06	200	572·70	194	572·45	194
May	572·59	206	572·37	209	573·29	216	573·19	226
June	572·66	207	572·44	209	573·13	176	573·14	222
July	572·56	205	572·34	208	573·44	176	572·97	230
August	572·49	206	572·27	208	573·44	199	572·66	220
September	572·50	206	572·28	209	573·38	273	572·55	217
October	572·15	201	571·93	203	572·97	256	572·29	205
November	571·92	204	571·70	207	572·54	223	572·01	177
December	571·55	201	571·33	203	572·35	226	571·98	186
1913—								
January	572·23	204	572·04	208	572·58	195	572·30	188
February	572·41	210	572·22	213	572·89	211	572·91	214
March	572·45	204	572·26	208	573·25	235	572·97	215
April	574·03	234	573·84	237	573·72	239	573·71	241
May	573·98	235	573·79	239	574·25	276	574·47	264
June	573·86	233	573·67	236	573·50	231	574·20	256
July	573·57	230	573·38	234	573·75	279	573·87	257
August	573·24	219	573·05	222	573·37	246	573·34	246
September	572·75	206	572·56	210	573·08	229	572·73	222
October	572·43	202	572·24	205	572·87	234	572·26	197
November	572·27	205	572·08	209	572·72	256	572·36	204
December	572·14	203	571·95	206	572·41	250	572·27	220
1914—								
January	572·05	197	571·89	201	572·27	212	572·10	180
February	571·71	191	571·55	194	572·17	196	572·11	180
March	571·48	181	571·32	185	572·05	176	571·93	176
April	572·18	197	572·02	200	572·45	176	572·24	186

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1914—								
May	572·90	212	572·74	216	573·18	201	573·17	225
June	573·03	215	572·87	218	573·47	201	573·54	237
July	572·82	211	572·66	215	573·27	176	573·35	241
August	572·56	206	572·40	209	573·08	176	572·87	227
September	572·32	201	572·16	205	572·96	176	572·46	213
October	572·06	194	571·90	197	572·66	176	572·10	184
November	571·47	195	571·31	199	572·28	178	571·80	176
December	571·41	185	571·25	188	572·10	178	571·68	176
1915—								
January	571·11	176	570·98	180	571·90	194	571·61	176
February	571·36	177	571·23	180	571·95	203	571·61	176
March	571·41	181	571·28	185	572·06	180	571·80	176
April	571·45	178	571·32	181	572·20	176	571·91	176
May	571·68	185	571·55	189	572·25	176	572·07	179
June	571·85	189	571·72	192	572·37	176	572·38	192
July	572·04	196	571·91	200	572·48	176	572·55	217
August	572·31	201	572·18	204	572·68	176	572·58	218
September	572·20	199	572·07	203	572·67	176	572·47	213
October	571·97	197	571·84	200	572·45	176	572·16	201
November	571·45	195	571·32	199	572·18	182	571·76	176
December	571·37	187	571·24	190	572·05	198	571·65	176
1916—								
January	571·66	198	571·56	203	572·44	212	571·89	176
February	571·99	198	571·89	202	572·64	221	572·44	194
March	571·87	191	571·77	196	572·86	232	572·58	200
April	572·45	204	572·35	208	573·03	235	572·79	208
May	572·86	214	572·76	219	573·49	243	573·29	228
June	573·28	221	573·18	225	573·51	243	573·65	239
July	573·22	220	573·12	225	574·10	268	573·64	249
August	572·82	212	572·72	216	573·49	255	573·23	238
September	572·29	205	572·19	210	573·25	240	572·60	219
October	571·89	199	571·79	203	572·86	230	572·26	197
November	571·67	194	571·57	199	572·65	263	572·05	179
December	571·52	193	571·42	197	572·25	230	572·28	222
1917—								
January	571·60	190	571·52	196	572·20	204	572·02	177
February	571·35	181	571·27	186	572·22	220	572·10	180
March	571·58	187	571·50	193	572·10	223	572·11	180
April	572·60	204	572·52	209	572·70	229	572·88	211
May	573·00	215	572·92	221	573·58	269	573·56	237
June	573·53	227	573·45	232	573·57	277	573·89	246
July	573·85	236	573·77	242	573·86	283	574·17	266
August	573·57	229	573·49	234	573·39	258	573·90	258
September	573·27	220	573·19	226	573·22	255	573·53	247
October	572·84	219	572·76	224	572·86	243	573·15	235
November	572·98	216	572·90	222	572·75	244	573·07	251
December	572·56	212	572·48	217	572·30	228	572·86	246
1918—								
January	571·89	196	571·81	202	571·82	188	572·03	177
February	571·65	187	571·57	192	571·60	198	571·79	176
March	572·25	198	572·17	204	571·88	198	572·08	179
April	572·26	195	572·18	200	572·35	176	572·59	200
May	572·17	198	572·09	204	572·58	176	572·51	197

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Disch (h)
1918—								
June	572·54	204	572·46	209	573·06	177	572·68	204
July	572·59	207	572·51	213	573·65	190	572·97	230
August	572·55	205	572·47	210	573·35	176	573·01	231
September	572·47	207	572·39	213	573·11	185	572·80	225
October	572·30	202	572·22	207	572·90	231	572·69	221
November	572·13	206	572·05	212	572·53	238	572·65	227
December	572·19	198	572·11	203	572·44	253	572·60	240
1919—								
January	572·18	208	572·11	214	572·27	207	572·29	188
February	572·21	201	572·14	206	572·45	203	572·46	195
March	572·59	203	572·42	209	572·52	227	572·64	202
April	573·05	215	572·98	220	572·77	232	573·08	220
May	573·68	228	573·61	234	573·43	251	573·62	239
June	573·77	230	573·70	235	573·62	199	573·88	246
July	573·44	225	573·37	231	573·37	223	573·67	251
August	573·14	221	573·07	226	573·29	176	573·14	235
September	572·75	213	572·68	219	572·97	176	572·70	221
October	572·47	205	572·40	210	572·61	176	572·34	203
November	572·22	206	572·15	212	572·47	241	572·14	186
December	571·87	198	571·80	203	572·18	187	572·08	198
1920—								
January	571·30	180	571·23	185	572·05	185	571·62	176
February	570·78	167	570·71	171	571·61	183	571·00	176
March	570·85	170	570·78	175	571·40	178	570·70	176
April	571·62	183	571·55	187	571·94	208	571·10	176
May	572·29	197	572·22	202	572·75	176	571·98	176
June	572·48	203	572·41	207	573·49	208	572·72	205
July	572·62	208	572·55	213	573·29	210	572·94	229
August	572·61	204	572·54	208	573·29	199	572·82	227
September	572·38	201	572·31	206	573·12	176	572·50	216
October	572·08	198	572·01	202	572·72	176	572·08	183
November	571·93	196	571·86	201	572·57	176	572·07	183
December	571·93	204	571·86	208	572·47	241	572·22	214
1921—								
January	571·94	197	571·88	202	572·00	201	572·16	183
February	571·88	192	571·82	196	571·94	187	572·29	188
March	572·11	194	572·05	199	572·60	236	572·37	191
April	572·79	208	572·73	212	572·60	176	572·88	212
May	573·08	214	573·02	219	573·12	185	573·35	230
June	573·00	213	572·94	217	573·29	176	573·41	232
July	572·85	212	572·79	217	573·22	176	573·15	235
August	572·47	204	572·41	208	572·97	176	572·67	221
September	572·16	200	572·10	205	572·59	176	572·18	190
October	571·74	192	571·68	196	572·39	188	571·90	176
November	571·79	186	571·73	191	572·41	183	571·87	176
December	571·74	199	571·68	203	572·27	214	572·02	190
1922—								
January	571·50	189	571·45	195	571·84	211	571·96	176
February	571·17	177	571·12	182	572·05	202	571·83	176
March	571·39	177	571·34	183	572·00	176	571·76	176
April	572·32	204	572·27	209	572·50	176	572·37	189
May	572·74	208	572·69	214	573·35	260	573·20	225
June	572·87	212	572·82	217	573·47	245	573·38	231

TABLE 11.—EFFECT OF REGULATION—LAKE ERIE—*Concluded*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1922—								
July	572·74	209	572·69	215	573·47	176	573·25	239
August	572·50	203	572·45	208	573·33	176	572·82	226
September	572·32	197	572·27	203	573·26	250	572·43	211
October	571·88	193	571·83	198	572·83	176	572·03	178
November	571·42	188	571·37	194	572·35	176	571·77	176
December	571·11	180	571·06	185	571·08	183	571·54	176
1923—								
January	571·16	177	571·12	182	571·79	200	571·47	176
February	570·83	170	570·79	174	571·77	188	571·38	176
March	571·00	174	570·96	179	571·73	177	571·23	176
April	571·49	182	571·45	186	571·95	176	571·55	176
May	571·82	189	571·78	194	572·32	176	572·06	178
June	572·00	195	571·96	199	572·46	176	572·42	193
July	571·99	192	571·95	197	572·42	176	572·53	217
August	571·69	188	571·65	192	572·55	176	572·16	189
September	571·51	182	571·47	187	572·35	176	571·95	176
October	571·23	177	571·19	181	572·22	176	571·79	176
November	570·96	174	570·92	179	571·96	176	571·55	176
December	571·25	183	571·21	187	571·87	178	571·55	176
1924—								
January	571·27	194	571·26	201	571·95	176	571·81	176
February	571·31	176	571·30	182	572·25	206	572·04	177
March	571·22	175	571·21	182	572·19	187	571·98	176
April	571·77	186	571·76	192	572·41	176	572·24	186
May	572·16	197	572·15	204	572·93	176	572·76	207
June	572·30	200	572·29	206	573·22	176	573·03	218
July	572·44	204	572·43	211	573·40	176	573·00	231
August	572·15	198	572·14	204	573·37	176	572·71	222
September	571·95	192	571·94	199	573·11	176	572·26	197
October	571·70	187	571·69	193	572·78	176	572·00	176
November	571·06	185	571·05	192	572·29	176	571·71	176
December	570·78	180	570·77	186	571·78	176	571·38	176
1925—								
January	570·62	164	570·61	170	571·67	202	571·30	176
February	570·50	162	570·49	167	571·45	180	571·11	176
March	570·92	170	570·91	176	571·69	176	571·17	176
April	571·32	175	571·31	180	572·07	176	571·57	176
May	571·31	178	571·30	184	572·26	176	571·81	176
June	571·18	177	571·17	182	572·12	176	571·76	176
July	571·12	176	571·11	182	571·97	176	571·70	176
August	571·08	172	571·07	177	571·82	176	571·66	176
September	570·94	170	570·93	176	571·65	176	571·58	176
October	570·60	169	570·59	174	571·33	176	571·32	176
November	570·45	171	570·44	177	571·01	176	571·02	176
December	570·39	172	570·38	177	570·91	176	570·91	176

TABLE 12.—EFFECT OF REGULATIONS—LAKE ONTARIO

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1860—								
January	246·58	....	246·80	....	....	....	....	....
February	246·72	....	246·94	....	....	....	....	....
March	246·77	....	247·00	....	....	....	....	....
April	246·80	....	247·03	....	....	....	....	....
May	247·03	....	247·27	....	....	....	....	....
June	247·57	283	247·79	274	....	....	247·20	266
July	247·82	285	248·05	277	....	....	247·67	297
August	247·26	283	247·51	274	....	....	247·35	296
September	246·86	277	247·09	269	....	....	246·63	271
October	246·67	267	246·89	258	....	....	246·32	274
November	246·75	273	246·98	264	....	....	245·95	273
December	246·73	269	246·95	260	....	....	245·76	279
1861—								
January	246·44	244	246·65	235	....	....	245·55	202
February	246·56	243	246·78	234	....	....	245·53	204
March	247·01	251	247·25	243	....	....	245·93	229
April	247·23	285	247·47	277	....	....	246·07	245
May	248·18	305	248·46	297	....	....	246·85	262
June	248·54	310	248·84	301	....	....	247·96	286
July	248·32	309	248·61	301	....	....	248·25	327
August	248·07	302	248·35	294	....	....	247·85	322
September	247·60	293	247·86	284	....	....	247·41	312
October	247·81	294	248·08	286	....	....	247·03	314
November	247·82	292	248·09	284	....	....	246·88	310
December	247·61	297	247·87	288	....	....	246·70	303
1862—								
January	247·11	259	247·35	250	....	....	246·45	209
February	246·69	248	246·91	239	....	....	246·21	209
March	247·18	247	247·67	238	....	....	248·38	235
April	248·08	296	248·36	287	....	....	246·85	259
May	248·88	318	249·29	310	....	....	247·72	290
June	248·62	312	248·92	303	....	....	248·19	291
July	248·72	310	249·02	301	....	....	248·15	327
August	248·26	301	248·55	293	....	....	247·83	321
September	247·61	290	247·87	281	....	....	247·28	305
October	247·08	279	247·32	270	....	....	246·49	286
November	246·73	270	246·95	261	....	....	245·96	274
December	246·62	264	246·84	256	....	....	245·66	280
1863—								
January	246·77	247	247·00	238	....	....	245·70	205
February	246·83	242	247·06	234	....	....	245·92	207
March	246·91	245	247·14	236	....	....	246·22	233
April	247·63	283	247·89	275	....	....	246·62	260
May	248·03	299	248·31	291	....	....	247·28	276
June	248·18	301	248·46	292	....	....	247·64	278
July	247·77	293	248·06	284	....	....	247·66	297
August	247·31	285	247·56	277	....	....	247·12	284
September	246·93	276	247·16	267	....	....	246·58	270
October	246·74	266	246·96	257	....	....	246·27	271
November	246·56	264	246·78	256	....	....	245·45	225
December	246·57	261	246·79	253	....	....	245·48	271
1864—								
January	246·33	223	246·53	214	....	....	244·85	197

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1864—								
February	246·17	228	246·37	220	....	....	244·68	196
March	246·26	242	246·46	233	....	....	244·68	198
April	246·83	270	247·06	261	....	....	245·15	215
May	247·82	291	248·09	281	....	....	246·27	243
June	248·12	301	248·40	293	....	....	247·35	270
July	247·80	292	248·07	284	....	....	247·69	298
August	247·34	283	247·59	275	....	....	247·31	294
September	246·81	273	247·04	274	....	....	246·67	274
October	246·58	266	246·80	257	....	....	246·16	265
November	246·55	268	246·77	260	....	....	245·64	242
December	246·65	272	246·87	263	....	....	245·63	279
1865—								
January	247·08	245	247·32	236	....	....	245·66	206
February	247·23	225	247·47	216	....	....	246·17	209
March	247·38	242	247·63	234	....	....	246·38	236
April	247·46	284	247·72	275	....	....	246·37	247
May	247·62	288	247·88	280	....	....	246·53	251
June	247·66	288	247·92	280	....	....	246·85	254
July	247·51	283	247·77	275	....	....	247·15	270
August	246·90	273	247·13	264	....	....	247·04	280
September	246·29	260	246·49	252	....	....	246·38	259
October	246·07	251	246·26	242	....	....	245·87	246
November	245·82	246	245·99	238	....	....	245·50	230
December	245·66	244	245·84	236	....	....	245·19	227
1866—								
January	245·46	205	245·60	197	....	....	244·93	198
February	245·47	200	245·61	191	....	....	244·74	196
March	245·48	214	245·62	205	....	....	244·58	196
April	245·96	251	246·15	243	....	....	244·74	199
May	246·02	260	246·21	252	....	....	245·44	210
June	245·92	272	246·10	263	....	....	245·98	210
July	246·84	274	247·07	266	....	....	247·08	266
August	246·74	270	246·96	262	....	....	247·71	314
September	246·65	265	246·87	257	....	....	247·17	299
October	246·52	262	246·73	254	....	....	246·59	293
November	246·28	265	246·48	256	....	....	245·92	271
December	246·20	272	246·40	263	....	....	245·54	274
1867—								
January	245·95	238	246·14	230	....	....	245·37	202
February	245·92	238	246·10	229	....	....	245·34	203
March	246·62	246	246·84	237	....	....	245·81	227
April	247·52	283	247·78	274	....	....	246·46	258
May	248·21	300	248·49	292	....	....	247·36	279
June	248·48	307	248·78	299	....	....	248·00	286
July	248·11	298	248·36	290	....	....	248·20	325
August	247·48	285	247·74	277	....	....	247·54	306
September	246·98	272	247·22	263	....	....	246·77	279
October	246·33	256	246·53	248	....	....	246·06	258
November	245·59	249	245·74	241	....	....	244·99	198
December	244·83	234	245·12	225	....	....	244·66	195
1868—								
January	244·51	210	244·58	202	....	....	244·42	194
February	244·61	184	244·69	176	....	....	244·39	194

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1868—								
March	244·88	210	244·97	201	....	....	244·43	196
April	245·52	246	245·66	237	....	....	244·88	201
May	246·12	251	246·31	243	....	....	245·66	222
June	246·54	267	246·75	268	....	....	246·40	231
July	246·42	264	246·63	256	....	....	247·07	266
August	246·13	258	246·31	249	....	....	247·04	280
September	245·94	252	246·12	244	....	....	246·64	272
October	245·35	243	245·48	235	....	....	245·78	238
November	245·20	237	245·31	228	....	....	245·20	201
December	245·37	244	245·50	235	....	....	245·39	258
1869—								
January	245·22	217	245·33	208	245·98	206	245·06	199
February	245·34	197	245·45	188	245·97	206	245·07	199
March	245·56	196	245·71	188	246·13	213	245·06	199
April	246·09	259	246·28	251	246·27	200	245·07	211
May	246·75	276	246·98	268	247·42	236	246·07	237
June	246·97	282	247·21	273	247·80	300	246·88	256
July	247·29	288	247·54	280	247·89	330	247·45	286
August	247·35	288	247·60	280	248·09	330	247·77	318
September	247·17	284	247·41	275	247·72	324	247·54	318
October	247·08	280	247·32	271	247·33	310	247·00	305
November	246·68	272	246·90	264	246·82	297	246·29	286
December	248·85	267	247·08	259	246·44	296	245·63	278
1870—								
January	247·26	258	247·51	249	246·60	213	245·59	206
February	247·41	258	247·66	249	247·01	215	246·22	210
March	247·41	253	247·66	244	247·20	252	246·72	241
April	248·35	304	248·64	295	247·67	291	247·21	277
May	248·95	318	249.27	310	248·57	300	248·06	300
June	248·63	313	248·93	305	248·57	300	248·35	296
July	248·31	309	248·60	301	248·25	330	248·18	323
August	247·97	296	248·25	288	248·31	325	247·74	316
September	247·28	282	247·53	274	247·47	317	246·96	289
October	246·95	276	247·19	268	247·17	307	246·37	278
November	246·38	265	246·59	256	246·76	293	245·82	261
December	246·13	260	246·32	251	246·26	287	245·12	217
1871—								
January	246·06	231	246·25	222	246·20	208	245·33	201
February	245·89	227	246·07	219	246·30	200	245·19	200
March	246·09	243	246·28	234	246·92	244	245·23	202
April	246·67	270	246·89	261	246·93	280	245·71	233
May	247·12	278	247·36	269	247·31	283	246·45	249
June	247·06	278	247·30	270	247·58	266	246·90	257
July	246·91	275	247·14	266	247·64	278	246·98	262
August	246·46	265	246·69	257	247·56	297	246·90	274
September	246·12	257	246·31	249	247·11	218	246·42	261
October	245·62	249	245·77	241	246·65	209	245·84	242
November	245·21	235	245·32	227	246·35	212	245·13	199
December	244·90	227	244·99	218	245·99	200	244·93	198
1872—								
January	244·73	190	244·81	182	245·90	200	244·86	196
February	244·51	174	244·58	166	245·42	200	244·43	192
March	244·35	189	244·42	180	245·13	200	243·95	191

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1872—								
April	244·84	222	244·93	214	245·17	200	244·04	193
May	244·96	234	245·06	225	245·65	200	244·58	197
June	245·29	241	245·41	232	246·01	200	245·02	200
July	245·35	242	245·48	234	246·36	200	245·37	202
August	245·19	237	245·30	239	246·49	200	245·56	206
September	244·90	232	244·99	224	246·50	200	245·60	219
October	244·74	227	244·82	218	246·40	200	245·26	205
November	244·69	228	244·77	220	246·38	234	245·19	200
December	244·35	211	244·42	202	245·96	200	245·18	226
1873—								
January	244·26	192	244·32	183	245·80	200	244·72	196
February	244·37	194	244·44	185	245·65	200	244·61	195
March	244·50	200	244·57	192	245·51	200	244·62	199
April	246·40	254	246·61	246	246·55	264	245·59	231
May	246·96	273	247·20	264	247·25	300	246·69	257
June	246·91	275	247·10	267	247·16	236	246·99	261
July	246·87	273	247·10	265	247·57	257	247·13	269
August	246·58	266	246·80	258	247·58	313	247·15	286
September	246·15	260	246·35	251	247·21	290	246·62	271
October	245·73	249	245·89	241	246·50	251	246·05	257
November	245·62	246	245·77	237	246·39	291	245·35	215
December	245·79	251	245·96	243	246·33	292	245·40	259
1874—								
January	246·37	238	246·58	229	246·45	212	245·77	207
February	246·74	239	246·96	231	246·99	216	246·34	213
March	247·29	261	247·54	252	247·48	254	247·03	247
April	247·20	279	247·44	270	247·72	284	247·32	272
May	247·17	273	247·41	265	247·31	200	247·20	274
June	247·28	284	247·53	275	247·68	215	247·15	265
July	247·22	282	247·46	274	248·00	321	247·36	281
August	246·97	276	247·21	268	247·65	317	247·28	293
September	246·34	262	246·54	254	247·05	262	246·64	272
October	245·93	255	246·11	246	246·60	226	245·96	251
November	245·40	245	245·53	237	246·39	240	245·14	199
December	245·03	236	245·13	227	246·05	205	244·99	198
1875—								
January	244·72	203	245·00	195	245·96	200	244·91	196
February	244·38	177	244·45	168	245·92	200	244·52	194
March	244·65	197	244·73	188	245·71	200	244·12	194
April	245·41	238	245·54	230	246·39	200	244·55	198
May	245·70	250	245·86	242	246·70	201	245·33	205
June	245·87	253	246·05	244	247·55	204	245·69	206
July	245·93	255	246·11	246	247·75	230	246·17	220
August	245·75	250	245·92	242	247·65	285	246·65	261
September	245·55	242	245·70	234	247·10	293	246·41	261
October	245·27	238	245·39	229	246·60	235	245·94	294
November	245·10	233	245·20	224	246·04	264	245·47	226
December	244·90	229	244·99	220	246·05	281	245·09	211
1876—								
January	245·29	217	245·41	209	246·05	210	245·73	206
February	245·97	226	246·10	217	246·85	214	246·10	209
March	246·52	240	246·73	232	247·11	249	246·64	239
April	247·50	286	247·76	278	247·45	287	247·29	278

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1876—								
May	248·07	298	248·35	290	248·05	300	248·20	301
June	248·29	304	248·58	295	248·34	300	248·63	301
July	248·36	305	248·65	296	248·75	330	248·87	330
August	247·91	294	248·18	286	248·39	327	248·51	330
September	247·30	280	247·55	272	246·60	318	247·81	330
October	246·97	277	247·21	269	247·08	306	246·95	304
November	246·61	266	246·83	257	246·81	295	246·33	291
December	246·40	265	246·61	256	246·32	287	245·93	282
1877—								
January	245·91	226	245·09	217	246·20	....	245·59	203
February	245·63	224	245·78	216	....	....	245·17	199
March	245·78	230	245·95	222	....	....	245·12	202
April	246·46	262	246·67	253	....	....	245·59	225
May	246·54	266	246·75	257	....	....	246·12	238
June	246·42	265	246·63	256	....	....	246·36	230
July	246·45	266	246·66	257	....	....	246·70	247
August	246·20	259	246·40	251	....	....	246·88	272
September	245·77	249	245·94	241	....	....	246·36	258
October	245·37	238	245·50	229	....	....	245·72	235
November	245·25	237	245·37	228	....	....	245·33	213
December	245·38	240	245·51	232	....	....	245·44	265
1878—								
January	245·48	223	245·62	214	....	....	245·51	201
February	245·68	220	245·84	212	....	....	245·60	205
March	246·38	238	246·59	230	....	....	245·96	230
April	246·64	267	246·86	258	....	....	246·37	249
May	246·98	275	247·22	266	....	....	246·72	258
June	246·96	274	247·20	266	....	....	246·99	261
July	246·92	272	247·15	264	....	....	247·07	266
August	246·88	272	247·11	264	....	....	247·15	287
September	246·59	269	246·81	260	....	....	246·81	281
October	246·33	261	246·53	253	....	....	246·31	274
November	246·21	260	246·41	251	....	....	245·78	257
December	247·00	276	247·24	267	....	....	245·94	293
1879—								
January	246·80	243	247·03	234	....	....	246·26	207
February	246·46	245	246·67	236	....	....	245·99	206
March	246·33	234	246·53	226	....	....	245·84	227
April	246·70	267	246·92	259	....	....	245·66	227
May	246·81	272	247·04	264	....	....	246·13	238
June	246·81	272	247·04	263	....	....	246·44	234
July	246·67	268	246·89	260	....	....	246·76	250
August	246·31	259	246·51	250	....	....	246·83	270
September	245·91	252	246·09	244	....	....	246·34	257
October	245·47	242	245·61	233	....	....	245·58	226
November	245·10	234	245·20	225	....	....	245·01	198
December	245·11	230	245·21	221	....	....	245·04	204
1880—								
January	245·30	222	245·42	214	....	....	245·20	201
February	245·63	222	245·78	213	....	....	245·39	203
March	245·95	232	246·14	223	....	....	245·80	227
April	246·15	257	246·35	249	....	....	245·97	236
May	246·33	262	246·53	254	....	....	246·26	243

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Continued*

Stages in Feet above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1880—								
June	246·53	266	246·74	257	....	....	246·57	241
July	246·52	265	246·73	257	....	....	246·97	261
August	246·09	255	246·28	246	....	....	246·88	272
September	245·74	258	245·91	249	....	....	246·31	255
October	245·36	239	245·48	231	....	....	245·93	249
November	245·30	241	245·42	232	....	....	245·28	208
December	245·10	229	245·19	221	....	....	245·22	232
1881—								
January	244·73	186	244·81	177	....	....	244·65	194
February	244·72	195	244·80	186	....	....	244·21	193
March	245·39	218	245·52	209	....	....	244·35	196
April	245·80	248	245·97	239	....	....	244·88	200
May	245·99	252	246·18	244	....	....	245·51	214
June	246·20	257	246·40	249	....	....	246·12	217
July	246·30	259	246·50	251	....	....	246·78	251
August	245·98	252	246·17	243	....	....	246·90	274
September	245·39	242	245·52	233	....	....	246·27	253
October	245·19	235	245·30	226	....	....	245·70	234
November	245·19	235	245·30	226	....	....	245·36	216
December	245·20	236	245·31	228	....	....	245·52	277
1882—								
January	245·73	229	245·89	221	....	....	245·58	205
February	245·91	231	246·09	222	....	....	245·95	209
March	246·52	247	246·73	238	....	....	246·53	238
April	246·81	269	247·04	261	....	....	246·99	266
May	247·02	273	247·26	264	....	....	247·23	274
June	247·55	286	247·81	277	....	....	247·52	274
July	247·53	285	247·79	277	....	....	247·89	308
August	247·19	278	247·43	269	....	....	247·55	306
September	246·81	267	247·04	258	....	....	247·10	296
October	246·30	255	246·50	247	....	....	246·42	282
November	245·87	245	246·05	237	....	....	245·66	245
December	245·62	246	245·77	238	....	....	245·42	262
1883—								
January	245·30	211	245·42	203	....	....	245·00	198
February	245·35	192	245·48	184	....	....	244·73	196
March	245·60	213	245·75	204	....	....	244·54	197
April	246·15	253	246·35	245	....	....	244·93	204
May	246·79	268	247·02	260	....	....	245·84	227
June	247·49	284	247·75	275	....	....	246·93	258
July	248·03	293	248·33	284	....	....	247·77	302
August	247·84	289	248·11	281	....	....	247·98	329
September	247·37	279	247·62	270	....	....	247·45	314
October	246·94	268	247·17	260	....	....	246·87	311
November	246·69	265	246·91	257	....	....	246·06	284
December	246·56	263	246·78	254	....	....	245·87	282
1884—								
January	246·51	226	246·72	218	....	....	245·71	204
February	246·91	234	247·14	225	....	....	245·78	206
March	247·58	248	247·84	240	....	....	246·23	233
April	248·16	294	248·44	285	....	....	246·80	264
May	248·19	298	248·47	290	....	....	247·31	277
June	248·09	293	248·37	285	....	....	247·43	272

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1884—								
July	247·99	293	248·27	285	....	....	247·45	286
August	247·64	287	247·90	279	....	....	247·38	298
September	247·22	275	247·46	267	....	....	247·00	290
October	246·80	264	247·03	256	....	....	246·38	278
November	246·30	256	246·50	248	....	....	245·71	250
December	246·15	252	246·35	243	....	....	245·18	226
1885—								
January	246·15	228	246·35	219	....	....	245·28	200
February	245·88	212	246·06	204	....	....	245·14	198
March	245·59	209	245·74	200	....	....	244·75	198
April	246·27	241	246·47	233	....	....	245·08	208
May	247·07	272	247·31	263	....	....	245·87	230
June	247·44	281	247·69	273	....	....	246·93	258
July	247·58	283	247·84	274	....	....	247·45	286
August	247·44	276	247·69	268	....	....	247·54	306
September	247·20	273	247·44	265	....	....	247·24	302
October	247·02	268	247·26	269	....	....	246·77	305
November	247·07	269	247·31	260	....	....	246·09	286
December	247·24	276	247·48	267	....	....	246·21	298
1886—								
January	247·60	256	247·86	247	....	....	246·37	211
February	247·67	256	247·93	247	....	....	246·87	215
March	247·81	259	248·08	251	....	....	247·27	249
April	248·43	298	248·72	290	....	....	247·39	279
May	248·65	304	248·95	296	....	....	247·67	289
June	248·41	300	248·70	291	....	....	247·77	281
July	248·04	293	248·32	284	....	....	247·61	294
August	247·59	284	247·85	276	....	....	247·18	287
September	247·24	277	247·48	268	....	....	246·77	279
October	246·83	268	247·06	260	....	....	246·42	282
November	246·51	266	246·72	257	....	....	245·86	265
December	246·44	261	246·65	253	....	....	245·48	271
1887—								
January	246·16	233	246·36	224	....	....	245·27	202
February	246·92	258	247·15	249	....	....	245·52	206
March	247·43	264	247·68	256	....	....	246·43	236
April	247·64	288	247·87	280	....	....	246·92	268
May	248·20	296	248·48	288	....	....	247·52	285
June	248·16	296	248·44	288	....	....	247·83	282
July	247·88	289	248·15	281	....	....	247·70	298
August	247·38	277	247·63	268	....	....	247·18	287
September	246·76	265	246·99	256	....	....	246·61	261
October	246·37	258	246·58	250	....	....	245·89	246
November	246·02	246	246·21	238	....	....	245·36	217
December	245·75	242	245·92	233	....	....	244·94	198
1888—								
January	245·45	214	245·59	205	....	....	244·81	195
February	245·30	194	245·42	186	....	....	244·37	193
March	245·54	208	245·68	200	....	....	244·12	193
April	246·17	253	246·37	245	....	....	244·42	197
May	246·31	256	246·51	248	....	....	245·20	202
June	246·28	258	246·48	250	....	....	245·85	207
July	246·34	258	246·54	250	....	....	246·46	234

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1888—								
August	246·24	257	246·44	248			246·75	266
September	245·85	249	246·03	240			246·39	259
October	245·49	239	245·63	231			245·74	235
November	245·41	239	245·54	231			245·08	200
December	245·41	240	245·54	231			245·30	244
1889—								
January	245·62	226	245·77	217			245·57	203
February	245·77	212	245·94	204			245·57	202
March	245·93	220	246·11	212			245·53	215
April	246·17	256	246·37	248			245·58	222
May	246·32	258	246·52	249			245·92	232
June	246·63	267	246·85	259			246·35	229
July	246·82	270	247·05	262			246·95	260
August	246·57	265	246·79	256			247·19	288
September	246·07	253	246·26	244			246·52	266
October	245·57	239	245·72	230			245·68	232
November	245·18	234	245·29	226			245·02	199
December	245·72	245	245·88	237			245·25	237
1890—								
January	246·26	239	246·46	230			245·48	204
February	246·60	239	246·82	231			245·92	208
March	246·97	252	247·21	243			246·56	238
April	247·17	276	247·41	268			246·93	266
May	247·52	285	247·78	276			247·35	278
June	428·16	295	248·44	286			247·92	285
July	247·99	295	248·27	286			248·27	328
August	247·33	280	247·58	271			247·58	308
September	246·97	273	247·21	265			246·78	279
October	246·64	264	246·86	255			246·30	274
November	246·71	265	246·93	256			245·76	255
December	246·51	259	246·72	250			245·50	274
1891—								
January	246·19	232	246·39	224			245·10	199
February	246·45	233	246·66	224			245·05	201
March	246·99	247	247·23	239			245·49	213
April	247·47	283	247·73	274			246·21	246
May	247·24	279	247·48	270			246·70	257
June	246·83	268	247·06	260			246·64	244
July	246·55	266	246·77	257			246·45	234
August	246·11	255	246·30	247			246·53	254
September	245·68	245	245·84	236			245·83	230
October	245·04	230	245·14	221			245·14	198
November	244·44	222	244·51	213			244·68	195
December	244·43	221	244·50	212			244·49	195
1892—								
January	244·51	202	244·58	193			244·60	195
February	244·48	187	244·55	178			244·50	194
March	244·61	190	244·69	182			244·39	194
April	245·20	231	245·31	222			244·61	197
May	245·25	234	245·37	225			245·07	201
June	245·81	247	245·98	238			245·47	206
July	246·33	260	246·53	252			246·45	234
August	246·25	255	246·45	246			247·17	287

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1892—								
September	246·04	254	246·23	246	....	....	246·75	278
October	245·60	242	245·75	234	....	....	246·10	260
November	245·32	236	245·44	227	....	....	245·09	199
December	245·20	232	245·31	224	....	....	244·99	198
1893—								
January	244·87	201	244·96	192	....	....	244·87	196
February	244·77	183	244·86	174	....	....	244·57	194
March	245·25	199	245·37	190	....	....	244·50	196
April	245·99	249	246·18	240	....	....	244·96	208
May	247·13	275	247·37	266	....	....	246·05	236
June	247·37	282	247·62	274	....	....	247·04	262
July	247·11	277	247·35	268	....	....	247·20	273
August	246·57	262	246·79	254	....	....	246·91	274
September	246·31	259	246·51	250	....	....	246·41	262
October	245·78	247	245·95	239	....	....	245·60	227
November	245·37	238	245·50	230	....	....	245·00	198
December	245·23	233	245·34	225	....	....	244·89	198
1894—								
January	245·56	218	245·71	209	245·99	208	245·06	199
February	245·75	197	245·92	188	246·28	209	245·18	200
March	246·05	230	246·24	222	246·16	219	245·23	202
April	246·10	251	246·29	243	246·51	200	245·54	220
May	246·27	256	246·47	248	246·98	231	245·88	230
June	246·80	269	247·03	260	247·96	300	246·47	235
July	246·60	263	246·82	255	248·08	330	246·99	262
August	246·03	250	246·22	241	247·32	233	246·77	266
September	245·51	240	245·65	232	247·00	200	246·11	245
October	245·26	234	245·38	225	246·75	218	245·39	213
November	244·95	229	245·05	220	246·34	265	245·03	198
December	244·57	220	244·61	211	245·95	227	244·77	196
1895—								
January	244·50	196	244·57	187	245·94	200	244·60	194
February	244·44	178	244·51	170	246·09	200	244·32	192
March	244·33	181	244·39	172	245·72	200	244·03	191
April	244·87	224	244·96	215	245·73	200	244·09	194
May	245·00	229	245·10	220	246·27	200	244·71	197
June	244·89	226	244·98	218	246·47	200	244·93	199
July	244·59	220	244·77	211	246·39	200	244·89	196
August	244·35	217	244·42	108	246·18	200	244·73	195
September	244·00	208	244·05	200	245·81	200	244·43	193
October	243·67	200	243·70	192	245·48	200	244·12	190
November	243·41	194	243·43	185	244·92	200	243·73	189
December	243·43	194	243·45	185	245·30	200	243·72	190
1896—								
January	243·80	187	243·84	179	245·37	200	243·93	191
February	244·27	188	244·33	180	245·52	200	244·19	193
March	244·49	185	244·56	177	245·65	200	244·42	196
April	245·41	233	245·54	225	246·08	200	244·88	201
May	245·43	237	245·56	229	246·88	200	245·66	222
June	245·34	237	245·46	229	247·07	200	245·59	203
July	245·08	233	245·18	224	247·11	200	245·70	204
August	244·94	228	245·03	219	247·00	200	245·78	216
September	244·46	216	244·53	207	246·72	200	245·49	231

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge h)
1896—								
October	244·23	209	244·29	200	246·31	200	245·13	198
November	243·97	209	244·02	200	246·06	200	244·87	197
December	243·99	204	244·04	195	245·85	200	244·72	196
1897—								
January	243·87	187	243·91	178	245·75	200	244·66	194
February	243·83	182	243·87	173	245·32	200	244·31	193
March	244·30	193	244·36	184	245·73	200	244·29	194
April	244·96	229	245·06	220	246·00	200	244·69	200
May	245·41	239	245·54	231	246·52	200	245·58	218
June	245·62	245	245·77	236	246·89	200	246·21	222
July	245·61	242	245·76	233	247·18	200	246·69	246
August	245·60	242	245·75	233	247·30	211	246·84	270
September	245·10	228	245·19	220	246·98	209	246·33	256
October	244·47	215	244·54	207	246·31	200	245·26	214
November	244·41	211	244·48	203	246·08	200	244·82	197
December	244·47	215	244·54	207	246·06	207	244·76	197
1898—								
January	244·64	201	244·71	193	246·00	200	244·85	198
February	245·08	210	245·18	201	246·21	208	244·96	199
March	245·48	223	245·62	214	246·30	234	245·31	204
April	245·92	244	246·09	235	246·41	223	245·80	232
May	246·07	249	246·26	241	247·10	200	246·18	240
June	246·13	250	246·31	241	247·41	200	246·44	234
July	245·85	244	246·03	236	247·42	200	246·59	241
August	245·51	237	245·65	229	247·22	200	246·48	251
September	245·09	228	245·19	220	246·86	200	245·66	232
October	244·84	221	244·93	213	246·51	200	245·15	199
November	244·88	221	244·97	213	246·40	233	245·04	198
December	244·90	224	244·99	215	246·08	215	245·02	202
1899—								
January	244·98	205	245·08	196	245·90	200	245·01	198
February	244·88	198	244·97	189	245·92	200	244·76	197
March	245·14	210	245·24	201	246·01	200	244·72	198
April	245·69	241	245·85	232	246·30	200	245·14	210
May	245·94	247	246·12	238	247·32	210	245·92	232
June	246·07	251	246·26	243	247·61	251	246·34	228
July	245·92	246	246·10	238	247·68	273	246·64	244
August	245·46	234	245·60	226	247·40	259	246·53	254
September	244·95	224	245·05	216	246·97	221	245·79	228
October	244·55	215	244·63	207	246·68	255	245·04	198
November	244·42	213	244·59	205	246·40	290	244·82	197
December	244·36	215	244·43	207	246·22	247	244·78	197
1900—								
January	244·63	199	244·71	193	245·96	200	244·83	198
February	244·88	199	244·97	194	246·12	207	244·86	198
March	245·19	204	245·30	198	246·62	242	244·98	199
April	245·80	242	245·97	236	246·90	253	245·18	210
May	245·99	248	246·18	242	247·52	227	245·90	231
June	245·91	249	246·09	243	247·43	200	246·11	217
July	245·82	247	245·99	242	247·57	200	246·43	233
August	245·54	240	245·68	234	247·53	228	246·59	258
September	245·12	232	245·22	227	247·00	209	246·06	242

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1900—								
October	244·72	223	244·80	218	246·60	247	245·37	212
November	244·55	219	244·63	213	246·38	268	245·01	198
December	244·84	226	224·93	220	246·26	281	245·05	206
1901—								
January	244·68	205	244·78	200	245·98	206	245·13	199
February	244·62	200	244·72	196	245·95	200	244·98	198
March	244·39	198	244·48	193	245·78	200	244·83	199
April	245·63	237	245·80	233	246·38	200	245·36	219
May	245·91	246	246·11	242	247·58	268	246·32	245
June	245·99	249	246·20	245	247·40	210	246·45	234
July	245·74	244	245·92	239	247·91	209	246·35	229
August	245·42	237	245·57	233	247·50	226	246·21	238
September	245·10	231	245·22	227	247·10	200	245·84	230
October	244·65	223	244·83	219	246·57	207	245·28	206
November	244·28	213	244·36	208	246·20	200	244·92	198
December	244·36	216	244·45	212	246·10	212	244·85	198
1902—								
January	244·42	197	244·54	193	246·10	200	245·02	198
February	244·30	177	244·41	172	245·91	200	244·85	198
March	244·95	208	245·10	204	246·21	200	244·88	200
April	245·40	237	245·58	232	246·88	255	245·54	220
May	245·47	240	245·66	235	246·75	200	245·87	230
June	245·55	242	245·75	238	247·09	200	245·98	210
July	245·97	250	246·21	245	247·57	212	246·43	243
August	246·11	251	246·35	247	247·81	297	247·18	287
September	245·66	244	245·87	239	246·80	209	246·84	282
October	245·42	237	245·60	233	246·51	206	246·20	267
November	245·05	230	245·20	226	246·22	223	245·46	226
December	244·89	225	245·03	221	246·00	219	245·08	210
1903—								
January	244·92	209	245·08	205	246·16	200	245·19	200
February	245·16	207	245·34	204	246·17	210	245·17	201
March	245·75	225	245·91	222	246·72	246	245·47	212
April	246·44	258	246·55	254	247·32	282	246·16	246
May	246·56	261	246·62	257	247·28	235	246·78	260
June	246·44	257	246·45	254	247·43	200	247·01	262
July	246·59	260	246·55	257	247·67	227	247·09	266
August	246·35	256	246·26	253	247·71	304	247·17	287
September	246·07	251	245·93	248	247·02	303	246·68	274
October	245·72	240	245·53	236	246·75	292	246·26	271
November	245·36	227	245·12	224	246·20	234	245·29	209
December	245·11	220	244·82	216	246·07	200	244·93	197
1904—								
January	244·72	192	244·41	188	245·72	200	244·61	195
February	245·00	196	244·69	192	245·83	207	244·47	196
March	245·63	207	245·32	203	246·50	245	244·80	201
April	247·00	255	246·69	251	247·25	286	245·65	235
May	247·61	270	247·30	266	247·90	300	246·87	263
June	247·87	277	247·56	273	247·94	300	247·56	275
July	247·89	279	247·58	275	247·91	330	247·84	306
August	247·64	275	247·33	271	247·77	317	247·65	312
September	247·25	266	246·94	262	247·17	296	247·04	293
October	246·87	257	246·56	253	246·60	217	246·64	296

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1904—								
November	246·36	245	246·05	241	246·22	246	245·44	223
December	245·81	223	245·50	219	245·83	200	244·95	198
1905—								
January	245·79	198	245·50	194	245·76	200	244·94	197
February	245·49	205	245·20	201	245·38	200	244·57	194
March	245·29	199	245·00	195	245·79	200	244·35	194
April	246·13	242	245·84	238	246·12	200	244·63	199
May	246·25	244	245·96	240	247·07	200	245·42	210
June	246·59	251	246·30	247	247·47	241	245·99	210
July	246·98	260	246·69	256	247·95	330	246·89	257
August	246·90	259	246·61	255	247·78	320	247·47	292
September	246·75	256	246·46	252	247·14	301	246·89	285
October	246·45	250	246·16	246	246·64	288	246·36	278
November	246·07	243	245·78	239	246·15	247	245·52	231
December	245·88	237	245·59	233	246·10	255	245·31	246
1906—								
January	246·13	229	245·86	225	246·07	207	245·07	199
February	246·10	221	245·83	217	246·31	208	245·20	200
March	245·91	218	245·63	214	246·13	227	245·25	201
April	246·25	243	245·98	238	246·42	200	245·44	217
May	246·36	247	246·09	243	247·08	200	245·85	227
June	246·41	249	246·14	245	247·35	200	246·14	218
July	246·58	252	246·31	247	247·60	206	246·62	242
August	246·27	245	246·00	240	247·65	243	246·85	270
September	245·81	236	245·54	232	246·83	200	246·26	257
October	245·52	233	245·25	229	246·49	200	245·64	229
November	245·59	231	245·32	227	246·42	246	245·34	214
December	245·71	229	245·44	225	246·10	282	245·47	270
1907—								
January	246·34	212	246·10	209	246·21	208	245·68	204
February	246·47	218	246·23	215	246·40	210	245·79	205
March	246·47	224	246·23	220	246·56	238	245·81	227
April	246·86	256	246·62	253	246·70	200	245·84	234
May	247·09	262	246·85	259	247·34	200	246·24	242
June	247·12	263	246·88	260	247·70	216	246·61	242
July	247·12	265	246·88	261	247·70	229	246·89	257
August	246·90	260	246·66	257	247·72	315	247·02	279
September	246·50	251	246·26	247	247·00	271	246·57	269
October	246·40	249	246·16	246	246·78	299	246·16	265
November	246·33	247	246·09	243	246·58	277	245·71	250
December	246·33	247	246·09	243	245·94	267	245·52	274
1908—								
January	246·73	221	246·52	217	246·12	207	245·40	202
February	246·99	218	246·78	214	246·18	210	245·54	204
March	247·39	223	247·18	220	246·80	242	245·88	228
April	248·02	281	247·81	277	246·93	285	246·17	248
May	248·46	292	248·25	289	248·00	300	247·03	268
June	248·62	294	248·41	291	247·80	297	247·71	279
July	248·34	289	248·13	286	247·63	279	247·90	309
August	247·95	279	247·74	276	247·52	303	247·45	301
September	247·14	264	246·93	260	246·91	201	246·69	274
October	246·44	249	246·23	245	246·40	200	245·81	241
November	245·92	239	245·71	236	246·08	200	245·05	198
December	245·51	230	245·30	227	245·73	200	244·76	195

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1909—								
January	245·17	203	244·99	201	245·42	200	244·51	194
February	245·28	197	245·10	194	245·72	200	244·36	194
March	245·70	211	245·52	208	245·70	200	244·43	196
April	246·18	243	246·00	240	246·58	200	244·84	203
May	247·16	262	246·98	259	247·52	247	245·85	230
June	247·30	267	247·12	264	247·71	262	246·81	253
July	247·16	264	246·98	262	247·40	200	247·13	269
August	246·82	257	246·64	254	247·38	212	247·09	282
September	246·28	245	246·10	242	247·00	207	246·52	266
October	245·84	237	245·66	235	246·61	203	245·85	243
November	245·35	225	245·17	222	246·27	200	245·16	199
December	245·21	224	245·03	221	246·06	200	244·95	198
1910—								
January	244·94	198	244·79	195	246·02	200	244·93	197
February	245·03	188	244·88	186	245·90	206	244·69	198
March	245·75	214	245·60	212	246·52	238	244·93	200
April	245·97	238	245·82	235	246·56	204	245·38	216
May	246·42	249	246·27	246	247·02	200	245·94	232
June	246·46	250	246·31	247	247·40	200	246·39	230
July	246·29	247	246·14	244	247·51	200	246·67	246
August	246·05	243	245·90	241	247·48	219	246·67	262
September	245·70	232	245·55	230	247·19	232	246·17	248
October	245·38	227	245·23	224	246·56	205	245·39	213
November	245·15	221	245·00	218	246·25	200	244·99	198
December	244·98	216	244·74	214	246·02	200	244·80	196
1911—								
January	244·77	194	244·64	192	245·87	200	244·67	195
February	244·86	191	244·73	188	245·65	200	244·52	194
March	244·96	197	244·83	194	245·80	200	244·51	196
April	245·44	225	245·31	223	246·07	200	244·76	198
May	245·60	232	245·47	230	246·52	200	245·28	202
June	245·66	233	245·53	231	246·80	200	245·50	203
July	245·54	232	245·41	230	246·80	200	245·69	204
August	245·19	224	245·06	221	246·78	200	245·72	214
September	244·88	215	244·75	213	246·52	200	245·30	203
October	244·62	212	244·49	210	246·32	200	245·05	198
November	244·50	213	244·37	210	246·08	200	244·85	197
December	244·63	214	244·50	211	246·00	203	244·79	198
1912—								
January	244·76	192	244·65	191	246·00	200	245·00	198
February	244·87	181	244·76	180	246·00	206	244·87	198
March	245·10	189	244·99	187	246·08	200	244·79	199
April	246·32	237	246·21	235	246·68	243	245·35	219
May	246·82	254	246·71	253	247·33	274	246·32	245
June	247·34	269	247·23	267	247·67	234	247·13	264
July	247·01	259	246·90	258	247·75	231	247·43	284
August	246·66	253	246·55	252	247·35	233	247·05	281
September	246·38	248	246·27	246	247·16	309	246·53	266
October	246·17	244	246·06	243	246·90	301	246·10	260
November	246·08	242	245·97	241	246·68	291	245·76	255
December	246·11	244	246·00	242	246·26	286	245·18	226
1913—								
January	246·51	232	246·42	230	246·20	209	245·38	203

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1913—								
February........	246·75	239	246·66	238	246·61	212	245·79	206
March..........	246·71	234	246·62	232	246·98	250	246·27	234
April............	247·86	273	247·77	271	247·67	289	246·90	269
May............	247·97	278	247·88	277	248·06	300	247·57	286
June............	248·02	281	247·93	278	248·33	300	247·87	283
July............	247·83	278	247·74	277	247·92	328	247·95	311
August..........	247·31	266	247·22	265	247·48	284	247·47	302
September......	246·74	253	246·65	252	246·97	264	246·73	277
October.........	246·29	244	246·20	242	246·57	256	246·05	257
November......	246·06	243	245·97	241	246·40	290	245·42	222
December.......	245·91	240	245·82	238	246·20	284	245·41	262
1914—								
January.........	245·60	214	245·53	213	245·95	200	245·04	198
February........	245·87	202	245·80	201	246·20	206	244·92	198
March..........	245·67	203	245·60	202	246·20	200	244·81	198
April............	246·75	250	246·68	248	246·55	200	245·18	213
May............	246·95	257	246·88	256	247·47	269	246·08	237
June............	246·91	257	246·84	255	247·21	200	246·52	238
July............	246·72	253	246·65	251	247·59	200	246·85	254
August..........	246·33	246	246·26	244	247·45	206	246·84	270
September......	246·09	241	246·02	240	247·20	222	246·42	261
October.........	245·59	230	245·52	229	246·60	276	245·91	248
November......	245·25	227	245·18	226	246·18	200	245·09	198
December.......	244·83	216	244·76	215	245·85	200	244·77	196
1915—								
January.........	244·70	199	244·65	198	245·64	200	244·57	195
February........	244·99	191	244·94	190	245·85	206	244·63	196
March..........	245·27	208	245·22	207	246·15	211	244·78	197
April............	245·04	222	244·99	221	246·11	200	244·80	198
May............	245·15	222	245·10	221	246·20	200	244·92	198
June............	245·12	220	245·07	219	246·32	200	245·10	200
July............	245·13	222	245·08	221	246·34	200	245·31	203
August..........	245·43	228	245·38	227	246·43	200	245·88	222
September......	245·45	229	245·40	228	246·55	200	246·25	252
October.........	245·17	225	245·12	224	246·44	203	245·95	250
November......	244·94	219	244·89	218	246·15	200	245·36	216
December.......	244·78	213	244·73	212	245·96	204	244·91	198
1916—								
January.........	245·05	205	245·02	204	246·21	209	244·94	198
February........	245·41	204	245·38	203	246·50	211	244·95	198
March..........	245·46	201	245·43	200	246·79	245	245·08	201
April............	246·40	246	246·37	245	247·13	284	245·58	230
May............	247·13	262	247·10	262	247·80	300	246·58	253
June............	247·86	276	247·83	275	248·31	300	247·49	274
July............	247·93	278	247·90	277	248·60	330	248·05	317
August..........	247·36	267	247·33	266	248·21	323	247·60	309
September......	246·69	254	246·66	253	247·36	289	246·70	275
October.........	246·06	241	246·03	240	246·60	242	245·85	243
November......	245·65	231	245·62	230	246·28	258	245·11	198
December.......	245·37	224	245·34	223	246·35	264	244·88	199
1917—								
January.........	245·26	204	245·25	203	246·01	200	245·27	199
February........	245·08	205	245·07	205	246·05	207	244·97	198
March..........	245·17	207	245·16	207	246·35	240	244·89	200

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Continued*

Stages in Feet Above Mean Sea Level

Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1917—								
April	246·24	243	246·23	242	246·90	280	245·40	221
May	246·51	246	246·50	245	247·33	300	246·35	246
June	246·98	258	246·97	257	247·60	300	246·89	257
July	247·46	269	247·45	268	248·08	330	247·52	289
August	247·35	269	247·34	268	248·01	323	247·75	317
September	246·93	258	246·92	258	247·35	308	247·17	299
October	246·68	254	246·67	253	246·75	283	246·57	291
November	246·69	251	246·68	250	246·45	288	246·09	286
December	246·45	246	246·44	245	246·16	271	245·89	279
1918—								
January	246·07	217	246·08	216	245·65	200	245·50	201
February	245·98	212	245·99	211	245·45	200	245·14	201
March	246·61	228	246·62	227	245·88	209	245·31	204
April	247·17	259	247·18	258	246·64	223	245·88	236
May	247·13	261	247·14	260	247·02	200	246·41	248
June	247·01	260	247·02	259	247·35	200	246·42	233
July	246·85	258	246·86	257	247·57	213	246·55	239
August	246·43	249	246·44	248	247·42	219	246·69	262
September	246·20	244	246·21	243	247·15	230	246·45	262
October	246·00	238	246·01	237	246·70	274	246·10	260
November	246·00	240	246·01	239	246·44	287	245·90	268
December	245·89	236	245·90	235	246·13	284	245·68	279
1919—								
January	246·09	226	246·10	225	246·14	208	245·61	203
February	245·91	222	245·92	221	246·32	209	245·58	203
March	246·01	226	246·02	225	246·35	235	245·59	218
April	246·43	252	246·44	251	246·71	240	245·86	238
May	247·27	269	247·28	268	247·62	300	246·62	254
June	247·95	279	247·96	278	248·20	300	247·62	277
July	247·75	275	247·76	274	247·90	200	248·00	314
August	247·33	267	247·34	266	247·60	225	247·43	300
September	246·86	256	246·87	255	247·03	207	246·67	274
October	246·35	246	246·36	246	246·60	200	245·94	249
November	246·11	241	246·12	240	246·36	273	245·45	225
December	245·74	236	245·75	235	246·00	200	245·00	198
1920—								
January	245·31	201	245·32	201	245·81	200	244·97	196
February	245·01	192	245·02	192	245·45	200	244·47	194
March	245·05	197	245·06	197	245·38	200	244·35	194
April	245·55	232	245·56	232	245·61	200	244·64	198
May	245·60	231	245·61	231	246·50	200	245·18	200
June	245·56	230	245·57	230	246·58	200	245·24	202
July	245·70	234	245·71	234	246·99	200	245·59	238
August	245·62	231	245·63	231	247·40	235	246·16	236
September	245·47	229	245·48	229	247·10	219	246·20	250
October	245·29	226	245·30	226	246·68	217	245·89	246
November	245·23	220	245·24	220	246·32	218	245·28	208
December	245·40	227	245·41	227	246·08	282	245·24	234
1921—								
January	245·54	215	245·55	215	245·96	206	245·36	201
February	245·46	210	245·47	210	246·11	202	245·31	202
March	245·79	222	245·80	222	246·10	237	245·38	207
April	246·38	247	246·39	247	246·83	233	245·93	237
May	246·68	253	246·69	253	247·03	200	246·46	250
June	246·61	252	246·62	252	247·40	200	246·76	250
July	246·37	247	246·38	247	247·32	200	246·77	250

TABLE 12.—EFFECT OF REGULATION—LAKE ONTARIO—*Concluded*
Stages in Feet Above Mean Sea Level
Discharges in Thousand Second Feet

Year—Month	Actual conditions occurring in past as given in record		Computed conditions for present regimen without regulation New Welland Canal assumed complete Chicago diversion assumed at 8,500 c.f.s. Other lowerings from data compiled by U.S. Lake Survey		Complete regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete		Partial regulation system; assuming 8,500 c.f.s. diversion at Chicago and New Welland Canal complete	
	Monthly mean		Monthly mean		First of month	Monthly mean	First of month	Monthly mean
(a)	Stage (b)	Discharge (c)	Stage (d)	Discharge (e)	Stage (f)	Discharge (g)	Stage (i)	Discharge (h)
1921—								
August	245·93	238	245·94	238	247·08	200	246·64	260
September	245·43	228	245·44	228	246·68	200	246·05	242
October	245·11	221	245·12	221	246·27	200	245·29	206
November	244·85	210	244·86	210	246·10	200	244·92	197
December	244·83	215	244·84	251	246·00	230	244·76	197
1922—								
January	244·73	197	244·74	197	245·88	200	244·76	195
February	244·70	188	244·71	188	245·97	200	244·46	194
March	245·08	202	245·09	202	246·18	200	244·44	197
April	246·06	244	246·07	244	246·77	235	245·06	210
May	246·55	250	246·56	250	247·27	300	246·06	236
June	246·75	253	246·76	253	247·57	282	246·72	248
July	246·92	258	246·93	258	247·74	221	247·13	269
August	246·56	250	246·57	250	247·61	243	247·19	288
September	246·03	239	246·04	239	246·87	270	246·50	265
October	245·61	233	254·62	233	246·60	200	245·80	240
November	245·15	220	245·16	220	246·30	200	245·04	197
December	246·64	210	244·65	210	245·82	200	244·59	194
1923—								
January	244·50	190	244·54	190	245·60	200	244·34	193
February	244·47	188	244·48	188	245·58	200	244·12	192
March	244·74	199	244·75	199	245·67	200	244·16	194
April	245·33	227	245·34	227	246·03	200	244·62	198
May	245·62	230	245·63	230	246·65	200	245·25	201
June	245·93	236	245·94	236	247·08	200	245·72	206
July	245·80	232	245·81	232	247·32	200	246·11	217
August	245·41	226	245·42	226	247·21	200	246·29	242
September	245·03	217	245·04	217	246·92	200	245·64	220
October	244·65	208	244·66	208	246·62	205	245·09	198
November	244·34	203	244·35	203	246·25	200	244·80	197
December	244·47	206	244·48	206	246·13	200	244·74	197
1924—								
January	244·77	198	244·81	198	246·30	208	244·92	198
February	244·85	192	244·89	192	246·07	206	244·81	197
March	244·88	196	244·92	196	246·22	200	244·71	197
April	245·36	224	245·40	224	246·48	200	244·87	201
May	246·10	239	246·14	239	247·19	204	245·69	223
June	246·27	242	246·31	242	247·70	229	246·38	230
July	246·21	242	246·25	242	247·56	200	246·73	249
August	246·04	239	246·08	239	247·52	223	246·79	267
September	245·65	230	245·69	230	247·08	219	246·38	258
October	245·45	225	245·49	225	246·67	200	245·71	234
November	244·95	218	244·99	218	246·40	209	245·03	197
December	244·58	208	244·62	208	245·90	200	244·67	194
1925—								
January	244·22	169	244·26	169	245·51	200	244·35	193
February	244·41	176	244·45	176	245·50	200	244·13	194
March	245·20	201	245·24	201	245·88	200	244·50	198
April	245·61	226	245·65	226	246·48	219	245·15	204
May	245·65	228	245·69	228	246·71	200	245·55	216
June	245·42	225	245·46	225	246·88	200	245·53	204
July	245·21	220	245·25	220	247·16	200	245·77	204
August	244·90	215	244·94	215	247·08	200	245·64	209
September	244·56	207	244·60	207	246·92	207	245·38	207
October	244·32	201	244·36	201	246·67	217	245·10	198
November	244·31	205	244·35	205	246·28	203	244·92	198
December	244·55	208	244·59	208	246·39	258	245·09	211

TABLE 13.—REGULATION OF THE GREAT LAKES—PARTIAL LIST OF DAMAGES WHICH WOULD RESULT FROM HIGH WATER IN LAKES MICHIGAN AND HURON

Stage	—	Authority
580·6	This would flood some land along Main and Grand Calumet Rivers.	District Engineer, U.S. Engineer Office, Chicago, Ill.
581·0	Above this would seriously affect sewerage system, flood basements, flood docks of Standard Oil Co. and cause unwarranted damage at Green Bay.	District Engineer, U.S. Engineer Office, Milwaukee, Wis.
	Above this would: Seriously affect sewerage systems of Chicago and vicinity, cause excessive flooding of basements during hard rains, raise ground water level in low parts of city, reduce widths of bathing beaches, reduce clearance under bridges to the point where excessive number of openings would be necessary and thereby cause additional delay and confusion in street traffic.	District Engineer, U.S. Engineer Office, Chicago, Ill.
	Above this would affect operation of Great Lakes Power Co. Ltd., of Sault Ste. Marie, through loss of head, unless present head was maintained by raising Lake Superior.	District Engineer, Can. Dept. Public Works, Sault Ste. Marie, Mich.
	Above this might affect sewerage system of Naval Training Station.	District Engineer, U.S. Engineer Office, Chicago, Ill.
581·2	U.S. Weather Bureau at Alpena state that this would cause unwarranted damage to riparian interests in that locality.	District Engineer, U.S. Engineer Office, Detroit, Mich.
581·6	This would partially submerge the jetties in the Chicago Engineer District and endanger riparian interests during storms by causing additional sliding along high banks.	District Engineer, U.S. Engineer Office, Chicago, Ill.
	Above this would interfere with operations at docks and elevators of Canadian National Ry.	Vice-President, Canadian Nat'l Rys., Montreal, Que.
	Above this would interfere with operations at docks and elevators of Goderich Elev. & Transit Co., Goderich.	District Engineer, Can. Dept. Public Works, London, Ont.
582·0	Above this would seriously affect sewerage system of Menominee.	District Engineer, U.S. Engineer Office, Wilwaukee, Wis.
	Above this would necessitate raising draw bridges of Michigan Central Railroad at Michigan City and Calumet.	District Engineer, U.S. Engineer Office, Milwaukee, Wis.
	Above this would interfere with operations at majority of structures from French River to St. Marys River. They are constructed to render greatest efficiency with mean level of 581·0.	District Engineer, Can. Dept. Public Works, Sault Ste. Marie, Mich.
	U.S. States Weather Bureau at Alpena states that this would interfere with operations of navigation and commercial interests in that locality.	District Engineer, Engineer U.S. Office, Detroit, Mich.
	At Alpena, this would interfere with operations at wharves of Huron Contracting Co. and cause unwarranted damage to riparian interests.	District Engineer, U.S. Engineer Office, Detroit, Mich.
582·1	At Muskegon, this would interfere with operations at wharves of Standard Oil Co.	District Engineer, U.S. Engineer Office, Detroit, Mich.
	At Green Bay, this would interfere with operations at wharves of Standard Oil Co.	District Engineer, U.S. Engineer Office, Detroit, Mich.
582·6	Above this might damage city parks of Evanston..........	District Engineer, U.S. Engineer Office, Chicago, Ill.
583·0	This would affect sewarage system and flood some basements in Manitowoc.	District Engineer, U.S. Engineer Office, Milwaukee, Wis.
	Above this would cause unwarranted damage at Racine....	District Engineer, U.S. Engineer Office, Milwaukee, Wis.
	This would cause unwarranted damage at Holland..........	District Engineer, U.S. Engineer Office, Milwaukee, Wis.
	This would cause some damage due to flooding of basements in downtown section of Milwaukee.	City Engineer, Milwaukee, Wis.
	U.S. Weather Bureau at Alpena states that this would flood docks and do unwarranted damage in that locality.	District Engineer, U.S. Engineer Office, Detroit, Mich.
583·1	At Muskegon this would flood docks and do unwarranted damage to Standard Oil Co.	District Engineer, U.S. Engineer Office, Detroit, Mich.
583·5	This would flood docks and cause unwarranted damage to Huron Contracting Co., at Alpena.	District Engineer, U.S. Engineer Office, Detroit, Mich.
583·6	At Mackinac Island, this would: Flood docks and interfere with operations of Municipal Light and Power Co. Cause unwarranted damage to riparian interests.	District Engineer, U.S. Engineer Office, Detroit, Mich.
583·7	Above this, would flood docks and cause unwarranted damage and interfere with operations of Huron Transportation Co.	District Engineer, U.S. Engineer Office, Detroit, Mich.

TABLE 13.—REGULATION OF THE GREAT LAKES—PARTIAL LIST OF DAMAGES WHICH WOULD RESULT FROM HIGH WATER IN LAKES MICHIGAN AND HURON—*Concluded*

Stage	——	Authority
585·0	At Bay City, this would flood docks and do unwarranted damage and interfere with operations at wharves of Standard Oil Co.	District Engineer, U.S. Engineer Office, Detroit, Mich.
585·6	At Rogers, this would interfere with operations at wharves of Michigan Limestone and Chem. Co.	District Engineer, U.S. Engineer Office, Detroit, Mich.
	Above this would flood considerable lands on lake shore north of Chicago.	District Engineer, U.S. Engineer Office, Chicago, Ill.
586·6	At Rogers, this would flood docks and cause unwarranted damage to Michigan Limestone and Chem. Co.	District Engineer, U.S. Engineer Office, Detroit, Mich.
587·6	At Rogers, this would cause unwarranted damage to riparian interests.	District Engineer, U.S. Engineer Office, Detroit, Mich.

TABLE 14.—PARTIAL LIST OF DAMAGES WHICH WOULD RESULT FROM HIGH WATER IN LAKE ERIE

Stage	——	Authority
571·6	Below this would affect operation of Erie Lighting Co's Plant.	Superintendent, Power Stations, Erie Lighting Co., Erie, Pa.
571·1	Below this would affect operation of Cleveland Elec. Ill. Co's Plant.	Assistant to President Cleveland Elec. Ill. Co., Cleveland, Ohio.
572·3	Above this might inconvenience car ferry, Toronto, Hamilton and Buffalo Co., Port Maitland.	District Engineer, Can. Dept. Pub. Works, London, Ont.
572·8	National Tube Co., Lorain, believe levels above this would cause unwarranted erosion of south shore of lake.	Manager, National Tube Co., Lorain, Ohio.
572·9	Much increase above this would affect waste water drainage system, So. Buffalo Ry., Lackawanna.	Chief Engineer, So. Buffalo Ry. Co., Lackawanna, N.Y.
573·1	Above this would seriously interfere with operation of power plants, Cleveland Elec. Ill. Co.	Asst. to President, Cleveland Elec. Ill. Co., Cleveland, Ohio.
573·5	Above this may damage property, Lake Erie Coal Co., Rondeau and Port Stanley.	District Engineer, Can. Dept. Pub. Works, London, Ont.
574·0	Above this would:	
	Interfere with operations, Maple Leaf Milling Co., Port Colborne.	District Engineer, Can. Dept. Pub. Works, London, Ont.
	Delay loading and unloading of steamers and would flood pit of power-house Pittsburgh and Conneaut Dock Co., Conneaut.	General Superintendent Pittsburgh and Conneaut Dock Co., Conneaut, Ohio.
	Damage works, Ohio Public Service Co., Lorain, Ohio..	Division Manager, Ohio Public Service Co., Lorain, Ohio.
574·0	Affect drainage system, Bethlehem Steel Co., Lackawanna..	Chief Engineer, Bethelem Steel Co., Lackawanna, N.Y.
	Above this would interfere with operations of unloading plants, Erie R.R., Cleveland.	Vice-President, Erie R.R. Co., New York, N.Y.
574·2	Above this would flood turn-table pit, Can. Nat. Ry., Port Dover.	Chief Engineer, Central Region, Can. National Rys., Toronto, Ont.
574·3	Above this would halt operation of elevators, Washburn-Crosby Co., Buffalo.	General Superintendent, Washburn-Crosby Co., Buffalo, N.Y.
574·4	Above this might damage Larman Coal Co., Port Colborne..	District Engineer, Can. Dept Pub. Works, London, Ont.
575·0	Above this would:	
	Interfere with unloading operations, Penn. R.R., Sandusky.	Superintendent, Toledo Division, Pennsylvania R.R., Toledo, Ohio.
	Interfere with unloading operations, Penn. R.R. at Buffalo, Erie, Sandusky, Ashtabula and Cleveland, Ohio.	Assistant Chief Engineer, Pennsylvania R.R., Pittsburgh, Pa.
	Interfere with operations, National Tube Co., Lorain......	Manager, National Tube Co., Lorain, Ohio.
	Above this would cause unwarranted damage to property of Hammerill Paper Co.	Assistant Secretary, Hammermill Paper Co., Erie Pa.

TABLE 14.—PARTIAL LIST OF DAMAGES WHICH WOULD RESULT FROM HIGH WATER IN LAKE ERIE

Stage	—	Authority
575·0	Interfere with unloading operations, Buffalo, Creek Ry., Buffalo.	Buffalo Creek R.R., Buffalo, N.Y.
575·5	This would flood docks, coal storage, etc., Erie Lighting Co.	Superintendent, Power Stations, Erie Lighting Co., Erie, Pa.
575·5	Above this would:	
	Stop operation of Canadian Government Elevator, Port Colborne.	Superintendent, Gov't Elevator, Can. Dept. Railways and Canals, Port Colborne, Ont.
576·0	This would probably flood docks and yard, American Ship Bldg. Co., Lorain.	General Superintendent, American Ship Bldg. Co., Lorain, Ohio.
576·8	This would flood docks, East Side Iron Elev. Co., Toledo..	District Engineer, U.S. Engineer Office, Detroit, Mich.
577·0	This would:	
	Interfere with operations, East Side Iron Elev. Co., Toledo.	District Engineer, U.S. Engineer Office, Detroit, Mich.
	Flood docks and yard, Canadian National Ry. Port Dover.	Chief Engineer, Central Region, Can. National Rys., Toronto, Ont.
	Flood docks, U.S. Engineer Office, Toledo................	District Engineer, U.S. Engineer Office, Detroit, Mich.
577·3	This would flood dock, National Milling Co., Toledo........	District Engineer, U.S. Engineer Office, Detroit, Mich.
577·5	Considered by Pennsylvania R.R. as highest level which would be safe for Toledo Division.	Superintendent, Toledo Division, Pennsylvania R.R., Toledo, Ohio.
578·0	This would flood buildings and halt operations Hammermill Paper Co., Erie.	Assistant Secretary, Hammermill Paper Co., Erie, Pa.
	Above this would flood yard Ganson St. Freighthouse, Erie R.R., Buffalo.	Vice-President, Erie R.R. Co., New York, N.Y.
578·8	This would flood docks, Red Star Navigation Co., Cleveland.	District Engineer, U.S. Engineer Office, Detroit, Mich.
579·0	Above this would flood docks and property, Erie R.R., Buffalo.	Vice-President, Erie R.R. Co., New York, N.Y.
580·0	Above this would:	
	Cause some damage to property and overflow tracks Buffalo Creek Ry., Buffalo.	Buffalo Creek R.R., Buffalo, N.Y.
	Flood docks, Lehigh Valley R.R., Buffalo................	Superintendent, Lehigh Valley R.R. Co., Buffalo, N.Y.
580·8	This would flood docks, B. & O. R.R., Toledo.............	District Engineer, U.S. Engineer Office, Detroit, Mich.

TABLE 15—PARTIAL LIST OF DAMAGES WHICH WOULD RESULT FROM HIGH WATER IN LAKE ONTARIO

Stage	—	Authority
246·0	Above this, it is believed that numerous small private docks and boat houses on Lake Ontario and the St. Lawrence River above Galop Island would be flooded and damaged.	
	This would flood wharf and coal shed, A. Collier, Port Milford	District Engineer, Can. Dept. Public Works, Ottawa, Ont.
247·0	Above this, probably some docks and buildings at Clayton, Cape Vincent, Sackett's Harbour, Oswego, Fairhaven, Sodus Point, Charlotte, Olcott, Youngstown and Lewiston would be flooded and operations interfered with at others.	
	Above this would affect Central Island Park, Toronto.	
	This would flood dock and canning factory, Port, Milford Packing Co., Port Milford.	District Engineer, Can. Dept. Public Works, Ottawa, Ont.
	This would seriously affect drainage of cellars in lower section of Kingston.	City Engineer, Kingston.

TABLE 15—PARTIAL LIST OF DAMAGES WHICH WOULD RESULT FROM HIGH WATER IN LAKE ONTARIO—*Continued*

Stage	——	Authority
247·5	This would flood— Wharf and two coal sheds, Jas. Soward, Kingston; wharf and 2 coal sheds, Ault & Reynolds, Brockville; L. H. Dept., Can. Dept. of Marine, Prescott; wharf and warehouse, A. Collier, Port Milford; and wharf and siding, C.P.R. Co., Kingston; wharf, Mrs. Cooper at Bath; Farmers' wharf, South Bay.	District Engineer, Can. Dept. Public Works, Ottawa, Ont.
	Above this would damage plant of Lake Ontario Sand Co., Charlotte.	Secretary, Lake Ontario Sand Co., Charlotte, Rochester, N.Y.
	Above this would affect LaSalle Causeway, Kingston, Kingston Dry dock, and Belleville wharf.	District Engineer, Can. Dept. Public Works, Ottawa, Ont.
	This would flood piers of Geo. Hall Corp. Shipyard, Ogdensburg, N.Y.	Secretary, Geo. Hall Corp., Ogdensburg, N.Y.
248·0	Above this, probably some docks and buildings at Ogdensburg, Morristown and Alexandria Bay would be flooded and operations interfered with at other docks.	
	This would flood— Wharf, A. Anglin & Co., Kingston; wharf, Canadian Govt., Wellington; wharf and storehouse, A. Collier, Port Milford; wharf, storehouse and evaporator, factory, D. Wattham, Waupoos; cribwork and waterworks dock, City of Kingston; wharf and freight and coal sheds, J. Swift & Co., Kingston.	District Engineer, Can. Dept. Public Works, Ottawa, Ont.
	Above this would probably flood majority of docks and seriously interfere with operations at N.Y. Central wharves at Clayton, Cape Vincent and Sacketts Harbour.	
	Above this, breakwater at Sackett's Harbour probably could not be used for mooring vessels.	
	Above this would seriously interfere with operations at N.Y. Stage Barge Canal Terminals and 1,000,000 bush. elevator and at coal docks of N.Y.O. & W.R.R. and D.L. & W.R. R., at Oswego, N.Y.; coal dock of L.V.RR. at Fairhaven Little Sodus B; coal dock of Penn. RR. at Sodus Pt.; coal docks of N.Y.C.RR. at Charlotte; and docks of Niagara Nav. Co. on Niagara River.	
	Abcve this, the lake would probably break through the low narrow strips of sand which have been built up between the shoreward ends of the breakwaters and the higher ground, to protect the entrances to Little Sodus and Great Sodus B.; and through the strip which separates Sterling Creek Pond from the lake.	
	Thiw sould necessitate reconstructing government piers and breakwaters at Oswego, Little Sodus Bay, Sodus Bay, Charlotte and Olcott to retain their effectiveness.	
	Above this, Sand Point, in Sodus Bay, with numerous summer cottages of probably low value, would probably be flooded.	
	Above this would probably flood state road on strip of land which separates Irondequoit Bay from the lake.	
	Above this would probably necessitate raising fixed steel bridges, about 100 ft. in length, which carry N.Y.C.RR. and the state highway across entrance to Irondequoit Bay.	
	Above this would probably damage numerous summer cottages and private docks in Irondequoit Bay.	
	Above this would probably flood the greater parts of Summerville, Windsor Beach and Ontario Beach, with numerous summer cottages, at Charlotte.	
	Above this would probably affect electric railway (about 8 miles long), constructed on low strip of land across entrances to numerous small bays, between Charlotte and Manitou Beach.	
	Above this would probably flood part of beach with summer cottages at Olcott.	
248·5	This would flood:— Dock, Hosiery Mill, Kingston; Ferry dock, Kingston; Dock, Kingston Yacht Club, Can. Gov't. wharf, Rednerville; entrance piers, Can. Govt., Wellington; dock and 2 coal sheds, Frontenac Str. and Coal Co., Kingston; freight and passenger wharf, Massagagna; wharf, elevator and coal shed, Northport; wharf, Forester Lt.	District Engr., Can. Dept. Pub. Works, Ottawa, Ont.

TABLE 15—PARTIAL LIST OF DAMAGES WHICH WOULD RESULT FROM HIGH WATER IN LAKE ONTARIO—*Continued*

Stage	—	Authority
249·0	Above this, would probably flood majority of docks at Ogdensburg and Morristown, and seriously interfere with operations at docks of N.Y. Central RR. Terminal, at docks and 500,000 bush. elevator at Rutland R.R Terminal, and at docks of Standard Oil Co., Geo. Hall Corp., Algonquin Paper Corp., and Pulp Terminal, at Ogdensburg.	
	This would flood Central Island Park, Toronto.	
	This would flood—	
	Town dock, Gananoque; wharf and coal shed, R. Crawford, Kingston; Cribworks, C.P.RR.Co., Kingston; wharf, Dr. Williams, Geen Island; wharf and cattle barns, J. P. Wiser & Sons, Prescott.	District Engineer, Can. Dept. Public Works, Ottawa, Ont.
	This, at Oswego, would probably stop operations at N.Y. Stage Barge Canal Terminals and at N.Y.O. & W.RR. and O.L. & W.RR. coal docks; flood some foundations along lower part of Oswego River and large portions of Diamond Match Co.'s plant and yard and Standard Oil Co.'s. Lumber yard and mill; and reduce power head from 17 ft. to 14 ft., of mills on east bank of Oswego River below Bridge St. It also would reduce power head of 12,000 H.P. plant, under construction by General Development Co., from 15 ft. to about 12 ft.	
249·5	This would flood dock, L. H. Service, Rockport; 2 docks, J. Smart Mfg. Co., Brockville.	District Engineer, Can. Dept. Public Works, Ottawa, Ont.
	This would flood—	
	Water Works Pier, Corp. of Brockville; L. H. Dept. wharf, Can. Govt. Depart. Marine, Prescott; wharf and warehouse, Plum, Prescott; wharf, Buckley, Prescott; wharf, R. Weddell & Co., Trenton; Public wharf, Can. Govt. Trenton; Public Coal Dock, Can. Govt., Trenton; Anderson Dock, Belleville; wharf, Way & Gulliver, Picton; wharf and freight shed, Adolphns Town, wharf, Emerald; wharf, Stella; wharf, coal and freight shed, Robinson, Bath; Portsmouth, Brewery wharf; wharf, Portsmouth; wharves, Ty. siding and elevator, Montreal Transp. Co., Kingston; waterworks dock, Town of Gananoque; dock and freight shed, Gananoque; wharf, Can. Govt. Public Works Dept. Mallorytown; wharf, Laing Co., Brockville.	District Engineer, Can. Dept. Public Works, Ottawa, Ont.
250·0	This would flood—	
	2 wharves and 2 coal sheds, B. Power & Co., Trenton; dock, C.P.RR., Trenton; Allen's dock Belleville, coal wharf, Stevens, Napanee; Lights wharf, Napanee; wharf, Rankin, Collins Bay; Breakwater, Can. Govt., Portsmouth, Entrance to Can. Govt. drydock, with 2 travelling cranes, Kingston; Cribwork, Kingston; wharf and grain elevator, J. Richardson & Son, KingMton.	District Engineer, Can. Dept. Public Works, Ottawa, Ont
250·5	This would flood—	
	Wharf and coal storage bldgs. Trenton Cooperage Mills, Ltd.; public wharf, track and store house, Can. Govt. Belleville; wharf and coal sheds, G.T.RR., Belleville; Public wharves along side LaSalle Highway, Can. Govt., Dept. Public Works, Kingston wharves and boat house, Royal Militia College, Kingston; Public wharf, Can. Govt., Burnt Is.; wharf, coal and freight sheds, Taylor and Green Co., Gananoque, docks, Ry. sidings and freight shed, Thousand Island Ry. Co., Gananoque; Public wharf, Can. Govt., P.W. Dept., Gananoque; Public wharf Lansdown; Carnegie wharf, Rockport; Public wharf, Can. Govt., P.W. Dept., Brockville; wharf, siding, storehouse and derrick, C.P.RR. Co., Brockville; wharves, coal shed and shed, Buckley, Prescott; wharf, tracks and freight shed, C.P.RR.Co., Prescott.	District Engineer Can. Dept. Public Works, Ottawa, Ont.
251·0	Above this would probably flood parts of railroad terminals at Ogdensburg and flood or stop operations at principal docks at Ogdensburg, Morristown, Alexandria Bay, Clayton, Cape Vincent and Sackett's Harbour.	
	This would flood part of yard, Rutland RR. Ogdensburg.....	Rutland Railroad Co., Ogdensburg, N.Y.

TABLE 15—PARTIAL LIST OF DAMAGES WHICH WOULD RESULT FROM HIGH WATER IN LAKE ONTARIO—*Concluded*

Stage	——	Authority
251·0	Above this would flood inner wharves, Toronto.	
	Above this would probably affect line of New York Central Railroad between Ogdensburg and Morristown.	
	This would flood LaSalle Causeway, Kingston and Belleville wharf.	District Engineer, Can. Dept. Public Works, Ottawa, Ont
252·5	This would flood— Private cribwood, Kingston, wharf, railway siding and oil pipe line, C.P. Railroad, Brockville.	District Engineer, Can. Dept. Public Works, Ottawa, Ont.
253·0	This would probably flood all docks and all railroad terminals at Ogdensburg.	
	This would flood entire yard of Rutland Railroad, Ogdensburg.	Rutland Railroad Co., Ogdensburg, N.Y.
253·5	This would flood— Cribwork, Penitentiary and Gumis Taunery, Portsmouth, wharf and sheds, Can. Cement Co., Point Aune.	District Engineer, Can. Dept. Public Works, Ottawa, Ont.
254·5	This would flood— Breakwater, Can. Govt., Portsmouth; Dock, Eastern Milk Products Co., Gananoque; wharf and grain elevator, Prescott Elevator Co., Prescott.	District Engineer, Can. Dept. Public Works, Ottawa, Ont.

TABLE 17.—REGULATION OF THE GREAT LAKES

STORAGE AT DETERMINING POINTS ON STORAGE DISTRIBUTION CURVES, FOR REGLUATION WITH COMPLETE CONTROL OF ST. CLAIR RIVER

Month	Upper Limit—Regulation for Equal Navigable Depth					Highest Safe Stage Lower Limit—Regulation for Equal Flood Probability					A High Point on Curves Regulation for Equal Flood Probability				
	Lake Superior	Lake Michigan—Huron	Lake Erie	Lake Ontario	Total Storage	Lake Superior	Lake Michigan—Huron	Lake Erie	Lake Ontario	Total Storage	Lake Superior	Lake Michigan—Huron	Lake Erie	Lake Ontario	Total Storage
Jan.....	689	985	225	164	2,063	950	1,458	368	286	3,062	1,388	2,325	542	428	4,683
Feb.....	672	960	218	160	2,010	880	1,462	375	295	3,012	1,255	2,329	556	443	4,583
March..	746	1,066	243	177	2,232	880	1,611	416	325	3,232	1,255	2,523	641	508	4,927
April....	877	1,252	286	208	2,623	950	1,795	491	389	3,625	1,242	2,443	641	509	4,835
May....	987	1,409	322	234	2,952	1,071	1,945	519	413	3,948	1,357	2,619	656	543	5,175
June....	1,041	1,486	340	247	3,114	1,146	2,030	522	416	4,114	1,290	2,398	587	480	4,755
July....	1,048	1,497	342	248	3,135	1,208	2,012	505	406	4,131	1,365	2,380	562	466	4,773
Aug.....	1,017	1,453	332	242	3,044	1,248	1,940	480	372	4,040	1,562	2,612	590	483	5,247
Sept....	960	1,372	313	228	2,873	1,248	1,839	448	332	3,867	1,562	2,501	557	440	5,060
Oct.....	880	1,258	287	209	2,634	1,197	1,713	412	306	3,628	1,502	2,407	524	406	4,839
Nov....	796	1,138	260	189	2,383	1,120	1,589	382	286	3,377	1,570	2,597	542	424	5,133
Dec....	736	1,051	240	175	2,002	1,041	1,506	375	278	3,200	1,510	2,448	540	423	4,921

NOTE.—Datums used in computing above storages were Superior 599·6, Michigan-Huron 577·6, Erie 568·8 and Ontario 242·5. All storages in thousand second foot months.

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1860—						
June	283	247·70	274	247·28	....	247·28
July	285	247·54	277	247·12	279	247·09
August	283	247·06	274	246·64	269	246·68
September	277	246·76	269	246·34	262	246·47
October	267	246·71	258	246·29	257	246·43
November	273	246·74	264	246·32	272	246·37
December	269	246·58	260	246·16	300[1]	246·05
					216[2]	246·25
1861—						
January	244	246·50	235	246·08	210	246·49
February	243	246·78	234	246·36	223	246·91
March	251	247·12	243	246·70	242	247·26
April	285	247·70	277	247·28	268[1]	247·61
					302[2]	247·73
May	305	248·36	297	247·94	300	248·35
June	310	248·43	301	248·01	310	248·31
July	309	248·20	301	247·48	310	247·96
August	302	247·84	294	247·42	301	247·51
September	293	247·70	284	247·28	303	247·13
October	294	247·82	286	247·40	303	247·03
November	292	247·72	284	247·30	310	246·61
December	297	247·36	288	246·94	310[1]	246·29
					218[2]	246·54
1862—						
January	259	246·90	250	246·48	212	246·56
February	248	246·94	239	246·52	224	246·78
March	247	247·63	238	247·21	240	247·44
April	296	248·48	287	248·06	272[1]	247·96
					310[2]	248·24
May	318	248·75	310	248·33	310	248·50
June	312	248·67	303	248·25	310	248·34
July	310	248·49	301	248·07	310	248·05
August	301	247·94	293	247·52	301	247·40
September	290	247·34	281	246·92	292	246·66
October	279	246·90	270	246·48	265	246·28
November	270	246·68	261	246·26	261	246·07
December	264	246·70	256	246·28	239[1]	246·18
					217[2]	246·43
1863—						
January	247	246·80	238	246·38	212	246·85
February	242	246·87	234	246·45	227	247·00
March	246	247·27	236	246·85	244	247·30
April	283	247·83	275	247·41	269[1]	246·62
					303[2]	247·72
May	299	248·10	291	247·68	299	247·88
June	301	247·98	292	247·56	307	247·58
July	293	247·54	284	247·12	284	247·14
August	285	247·12	277	246·70	263	246·89
September	276	246·84	267	246·42	264	246·65
October	266	246·65	257	246·23	260	246·33
November	264	246·56	256	246·14	257	246·23
December	261	246·45	253	246·03	294[1]	245·92
					209[2]	246·14
1864—						
January	223	246·25	214	245·83	209	246·00
February	228	246·22	220	245·80	217	246·00
March	242	246·54	233	246·12	217	246·52
April	270	247·32	261	246·90	241[1]	247·03
					271[2]	247·35
May	291	247·97	281	247·55	277	248·05

[1] First half of month. [2] Second half of month.

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1864—						
June	301	247·96	293	247·54	310	247·83
July	292	247·57	284	247·15	291	247·34
August	283	247·08	275	246·66	266	246·95
September	273	246·70	274	246·28	263	246·71
October	266	246·56	257	246·14	259	246·55
November	268	246·60	260	246·18	273	246·43
December	272	246·86	263	246·44	302[1]	246·32
					218[2]	246·73
1865—						
January	245	247·16	236	246·74	214	247·31
February	225	247·30	216	246·88	233	247·23
March	242	247·42	234	247·00	247	247·18
April	284	247·54	275	247·12	263[1]	247·32
					276[2]	247·37
May	288	247·64	280	247·22	273	247·56
June	288	247·58	280	247·16	282	247·47
July	283	247·20	275	246·76	270	247·15
August	273	246·60	264	246·18	259	246·61
September	260	246·18	252	245·76	249	246·22
October	251	245·94	242	245·52	240	246·01
November	246	245·74	238	245·32	235	245·85
December	244	245·56	236	245·14	207[1]	245·94
					210[2]	246·02
1866—						
January	205	245·46	197	245·04	208	245·78
February	200	245·48	191	245·04	211	245·56
March	214	245·72	205	245·30	207	245·77
April	251	245·99	243	245·57	203[1]	246·16
					216[2]	246·46
May	260	245·97	252	245·55	221	246·82
June	272	246·38	263	245·96	241	247·51
July	274	246·79	266	246·37	269	247·87
August	270	246·70	262	246·28	277	247·58
September	265	246·58	257	246·16	288	247·07
October	262	246·40	254	245·98	280	246·57
November	265	246·24	256	245·82	275	246·18
December	272	246·08	263	245·66	283[1]	245·98
					215[2]	246·20
1867—						
January	238	245·94	230	245·52	210	246·31
February	238	246·27	229	245·85	220	246·75
March	246	247·07	237	246·65	240	247·51
April	283	247·86	274	247·44	274[1]	247·91
					208[2]	248·10
May	300	248·34	292	247·92	310	248·35
June	307	248·30	299	247·88	310	248·16
July	298	247·80	290	247·38	305	247·47
August	285	247·23	290	246·81	268	247·01
September	272	246·66	263	246·24	265	246·41
October	256	245·96	248	245·54	245	245·75
November	249	245·21	241	244·79	228	245·16
December	234	244·67	225	244·25	201[1]	245·04
					200[2]	244·93
1868—						
January	210	244·56	202	244·14	199	244·85
February	184	244·74	176	244·32	200	244·73
March	210	245·20	201	244·78	200	245·21
April	246	245·82	237	245·40	205[1]	245·72
					210[2]	246·20
May	251	246·33	243	245·91	211	247·10

[1] First half of month. [2] Second half of month.

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1868—						
June	267	246·48	268	246·06	256	247·40
July	264	246·28	256	245·85	268	247·05
August	258	246·04	249	245·62	252	246·77
September	252	245·64	244	245·22	246	246·35
October	243	245·28	235	244·86	234	246·00
November	237	245·28	228	244·86	226	246·02
December	244	245·30	235	244·88	220[1]	246·12
					217[2]	246·24
1869—						
January	217	245·28	208	244·86	210	246·20
February	197	245·45	188	245·03	219	245·99
March	196	245·82	188	245·40	217	245·99
April	259	246·42	251	246·00	207[1]	246·57
					234[2]	246·97
May	276	246·86	268	246·44	244	247·71
June	282	247·13	273	246·71	282	247·87
July	288	247·32	280	246·90	284	248·01
August	288	247·27	280	246·84	287	247·86
September	284	247·12	275	246·70	305	247·35
October	280	246·88	271	246·46	298	246·77
November	272	246·76	264	246·34	294	246·27
December	267	247·06	259	246·64	296[1]	246·27
					218[2]	246·75
1870—						
January	258	247·34	249	246·92	214	247·47
February	258	247·41	249	246·99	235	247·72
March	253	247·88	244	247·46	255	248·06
April	304	248·65	295	248·23	286[1]	248·51
					310[2]	248·81
May	318	248·79	310	248·37	310	248·95
June	313	248·47	305	248·05	310	248·56
July	309	248·14	301	247·72	310	248·12
August	296	247·62	288	247·20	300	247·44
September	282	247·12	274	246·70	290	246·74
October	276	246·66	268	246·24	269	246·26
November	265	246·26	256	245·84	251	245·92
December	260	246·10	251	245·68	208[1]	246·11
					217[2]	246·23
1871—						
January	231	245·98	222	245·56	210	246·27
February	227	246·00	219	245·58	220	246·27
March	243	246·40	234	245·98	226	246·77
April	270	246·91	261	246·49	253[1]	247·07
					277[2]	247·22
May	278	247·09	269	246·67	275	247·33
June	278	246·98	270	246·56	281	247·08
July	275	246·68	266	246·26	269	246·74
August	265	246·29	257	245·87	257	246·35
September	257	245·87	249	245·45	247	245·95
October	249	245·42	241	245·00	237	245·55
November	235	245·06	227	244·64	225	245·21
December	227	244·82	218	244·40	201[1]	245·20
					201[2]	245·19
1872—						
January	190	244·62	182	244·20	201	244·75
February	174	244·43	166	244·01	200	244·14
March	189	244·60	180	244·18	190	244·19
April	222	244·90	214	244·48	193[1]	244·47
					194[2]	244·75
May	234	245·12	225	244·70	197	245·33

[1] First half of month. [2] Second half of month.

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1872—						
June	241	245·32	232	244·90	198	245·95
July	242	245·27	234	244·85	219	246·09
August	237	245·04	239	244·62	229	245·98
September	232	244·82	224	244·40	230	245·68
October	267	244·72	218	244·30	223	245·52
November	228	244·52	220	244·10	220	245·32
December	211	244·33	202	243·91	202[1]	245·22
					202[2]	245·12
1873—						
January	192	244·34	183	243·92	201	244·91
February	194	244·44	185	244·02	201	244·81
March	200	245·46	192	245·08	200	245·75
April	254	246·73	246	246·31	204[1]	246·64
					241[2]	247·29
May	273	246·96	264	246·54	265	247·50
June	275	246·90	267	246·48	278	247·30
July	273	246·74	265	246·32	268	247·10
August	266	246·39	258	245·97	258	246·75
September	260	245·96	251	245·54	253	246·30
October	249	245·66	241	245·24	242	245·99
November	246	245·70	237	245·28	237	246·03
December	251	246·07	243	245·65	223[1]	246·33
					218[2]	246·67
1874—						
January	238	246·55	229	246·13	213	247·36
February	239	247·02	231	246·60	233	247·81
March	261	247·24	252	246·82	256	247·99
April	279	247·18	270	246·76	284[1]	247·87
					310[2]	247·59
May	273	247·22	265	246·80	288	247·34
June	284	247·24	275	246·82	273	247·39
July	282	247·10	274	246·68	274	247·25
August	276	246·66	268	246·24	264	246·85
September	262	246·14	254	245·72	259	246·24
October	255	245·66	246	245·24	243	245·80
November	245	245·20	237	244·78	229	245·44
December	236	244·88	227	244·46	203[1]	245·43
					203[2]	245·42
1875—						
January	203	244·56	195	244·14	203	245·00
February	177	244·51	168	244·09	202	244·52
March	197	245·04	188	244·62	198	244·93
April	238	245·58	230	245·16	204[1]	245·35
					204[2]	245·77
May	250	245·79	242	245·37	205	246·45
June	253	245·88	244	245·46	233	246·69
July	255	245·83	246	245·41	248	246·61
August	250	245·66	242	245·24	247	246·37
September	242	245·41	234	244·99	244	245·99
October	238	245·18	229	244·76	237	245·67
November	233	244·99	224	244·57	230	245·41
December	229	245·10	220	244·68	203[1]	245·57
					204[2]	245·72
1876—						
January	217	245·64	209	245·22	206	246·30
February	226	246·24	217	245·82	220	246·86
March	240	247·01	232	246·59	242	247·50
April	286	247·79	278	247·37	273[1]	247·92
					310[2]	248·11
May	298	248·19	290	247·77	310	248·26

[1] First half of month. [2] Second half of month

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1876—						
June	304	248·34	295	247·92	310	248·22
July	305	248·14	296	247·72	310	247·84
August	294	247·60	286	247·18	297	247·16
September	280	247·13	272	246·71	287	246·50
October	277	246·78	269	246·36	263	246·22
November	266	246·51	257	246·09	257	245·96
December	265	246·16	256	245·74	213[1]	246·05
					216[2]	246·13
1877—						
January	226	245·76	217	245·34	209	245·83
February	224	245·70	216	245·28	212	245·82
March	230	246·12	222	245·70	212	246·36
April	262	246·50	253	246·08	234[1]	246·66
					259[2]	246·81
May	266	246·48	257	246·06	255	246·82
June	265	246·45	256	246·03	256	246·80
July	266	246·34	257	245·92	257	246·69
August	259	245·98	251	245·56	255	246·28
September	249	245·56	241	245·14	247	245·78
October	238	245·30	229	244·88	234	245·46
November	237	245·32	228	244·90	228	245·48
December	240	245·43	232	245·01	204[1]	245·70
					206[2]	245·91
1878—						
January	223	245·58	214	245·16	207	246·15
February	220	246·04	212	245·62	218	246·54
March	238	246·52	230	246·10	235	246·95
April	267	246·81	258	246·39	261[1]	247·07
					276[2]	247·09
May	275	246·98	266	246·56	264	247·29
June	274	246·95	266	246·53	275	247·14
July	272	246·89	264	246·47	268	247·03
August	272	246·72	264	246·30	261	246·89
September	269	246·46	260	246·04	263	246·60
October	261	246·27	253	245·85	256	246·39
November	260	246·62	251	246·20	263	246·59
December	276	246·92	267	246·50	309[1]	246·48
					220[2]	246·93
1879—						
January	243	246·63	234	246·21	216	246·87
February	245	246·38	236	245·96	227	246·73
March	234	246·50	226	246·08	240	246·67
April	267	246·76	259	246·34	248[1]	246·87
					258[2]	247·01
May	272	246·85	264	246·40	253	247·21
June	272	246·72	263	246·33	261	247·17
July	268	246·50	260	246·08	259	246·93
August	259	246·11	250	245·69	249	246·55
September	252	245·68	244	245·26	241	246·15
October	242	245·26	233	244·84	233	245·74
November	234	245·08	225	244·66	223	245·59
December	230	245·21	221	244·79	205[1]	245·77
					206[2]	245·93
1880—						
January	222	245·46	214	245·04	207	246·27
February	222	245·77	213	245·35	220	246·49
March	232	246·03	223	245·61	233	246·63
April	257	246·20	249	245·78	244[1]	246·74
					249[2]	246·82
May	262	246·39	254	245·97	240	247·18

[1] First half of month. [2] Second half of month

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1880—						
June	266	246·52	257	246·10	259	247·29
July	265	246·30	257	245·88	266	246·95
August	255	245·90	246	245·48	255	246·44
September	258	245·52	249	245·10	245	245·99
October	239	245·29	231	244·87	235	245·70
November	241	245·18	232	244·76	227	245·65
December	229	244·92	221	244·50	205[1]	245·63
					205[2]	245·61
1881—						
January	186	244·74	177	244·32	205	245·09
February	195	245·06	186	244·64	202	245·21
March	218	245·60	209	245·18	204	245·81
April	248	245·90	239	245·48	212[1]	246·13
					226[2]	246·35
May	252	246·10	244	245·68	222	246·83
June	257	246·24	249	245·82	250	246·95
July	259	246·12	251	244·70	257	246·75
August	252	245·68	243	244·26	250	246·23
September	242	245·29	233	244·87	239	245·77
October	235	245·18	226	244·75	229	245·62
November	235	245·18	226	244·76	230	245·57
December	236	245·46	228	245·04	204[1]	245·86
					207[2]	246·14
1882—						
January	229	245·82	221	245·40	209	246·65
February	231	246·20	222	245·78	225	247·00
March	247	246·66	238	246·24	244	247·39
April	269	246·92	261	246·50	271[1]	247·45
					292[2]	247·37
May	273	247·28	264	246·86	279	247·55
June	286	247·52	277	247·10	287	247·67
July	285	247·36	277	246·94	285	247·41
August	278	247·00	269	246·58	270	247·03
September	267	246·56	258	246·14	271	246·43
October	255	246·09	247	245·67	251	245·91
November	245	245·74	237	245·32	239	245·53
December	246	245·46	238	245·04	204[1]	245·61
					205[2]	245·67
1883—						
January	211	245·35	203	244·93	205	245·53
February	192	245·50	184	245·08	207	245·39
March	213	245·88	204	245·46	205	245·77
April	253	246·46	245	246·04	206[1]	246·29
					225[2]	246·70
May	268	247·14	260	246·72	236	247·68
June	284	247·76	275	247·34	284	248·19
July	293	247·93	284	247·51	299	248·18
August	289	247·60	281	247·18	288	247·76
September	279	247·14	270	246·72	287	247·08
October	268	246·80	260	246·38	273	246·58
November	265	246·62	257	246·20	269	246·58
December	263	246·53	254	246·11	294[1]	245·94
					211[2]	246·16
1884—						
January	226	246·70	218	246·28	209	246·44
February	234	247·22	225	246·80	222	247·00
March	248	247·86	240	247·44	244	247·59
April	294	248·18	285	247·76	275[1]	247·81
					310[2]	247·81
May	298	248·14	290	247·72	309	247·52

[1] First half of month. [2] Second half of month.

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1884—						
June	293	247·98	285	247·56	293	247·26
July	293	247·76	285	247·34	278	247·12
August	287	247·44	279	247·02	268	246·93
September	275	247·01	267	246·59	270	246·47
October	264	246·55	256	246·13	254	246·03
November	256	246·22	248	245·80	247	245·71
December	252	246·14	243	245·72	206[1]	245·91
					208[2]	246·09
1885—						
January	228	246·00	219	245·58	209	246·08
February	212	245·73	204	245·31	218	245·63
March	209	245·93	200	245·51	208	245·73
April	241	246·67	233	245·25	210[1]	246·24
					239[2]	246·56
May	272	247·26	263	246·84	242	247·42
June	281	247·51	273	247·09	286	247·51
July	283	247·50	274	247·08	287	247·33
August	276	247·32	268	246·90	275	247·05
September	273	247·12	265	246·70	280	246·66
October	268	247·04	259	246·62	269	246·46
November	269	247·16	260	246·74	279	246·35
December	276	247·42	267	247·00	299[1]	246·27
					218[2]	246·71
1886—						
January	256	247·64	247	247·22	214	247·35
February	256	247·74	247	247·32	233	247·63
March	259	248·12	251	247·70	253	247·98
April	298	248·54	290	248·12	284[1]	248·23
					310[2]	248·31
May	304	248·54	296	248·12	310	248·13
June	300	248·24	291	247·82	310	247·59
July	293	247·82	284	247·40	294	247·05
August	284	247·42	276	247·00	270	246·73
September	277	247·10	268	246·68	264	246·47
October	268	246·73	260	246·31	259	246·11
November	266	246·46	257	246·04	251	245·92
December	261	246·30	253	245·88	209[1]	246·13
					217[2]	246·29
1887—						
January	233	246·54	224	246·12	210	246·70
February	258	247·18	249	246·76	225	247·64
March	264	247·54	256	247·12	254	248·03
April	288	247·92	280	247·50	285[1]	248·18
					310[2]	248·18
May	296	248·18	288	247·76	310	248·16
June	296	248·02	288	247·60	310	247·72
July	289	246·62	281	247·20	291	247·20
August	277	247·06	268	246·60	269	246·62
September	265	246·56	256	246·14	255	246·13
October	258	246·20	250	245·78	243	245·85
November	246	245·88	238	245·46	237	245·54
December	242	245·60	233	245·18	204[1]	245·59
					205[2]	245·63
1888—						
January	214	245·37	205	244·95	205	245·41
February	194	245·42	186	245·00	205	245·22
March	208	245·86	200	245·44	204	245·61
April	253	246·20	245	245·72	208[1]	246·01
					219[2]	246·33
May	256	246·26	248	245·84	221	246·72

[1] First half of month. [2] Second half of month.

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1888—						
June	258	246·31	250	245·89	246	246·82
July	258	246·29	250	245·87	256	246·72
August	257	246·04	248	245·62	250	246·44
September	249	245·67	240	245·25	247	245·59
October	239	245·46	231	245·04	236	245·71
November	239	245·42	231	245·00	228	245·70
December	240	245·52	231	245·10	206[1]	245·90
					207[2]	246·10
1889—						
January	226	245·69	217	245·27	209	246·38
February	212	245·84	204	245·42	221	246·32
March	220	246·05	212	245·63	227	246·33
April	256	246·24	248	245·82	232[1]	246·53
					249[2]	246·62
May	258	246·48	249	246·06	239	246·98
June	267	246·72	259	246·30	256	247·26
July	270	246·70	262	246·28	271	247·12
August	265	246·29	256	245·87	263	246·62
September	253	245·79	244	245·37	253	246·01
October	239	245·37	230	244·95	239	245·47
November	234	245·46	226	245·04	226	245·56
December	245	246·00	237	245·58	204[1]	246·04
					216[2]	246·44
1890—						
January	239	246·46	230	246·00	212	247·09
February	239	246·76	231	246·34	230	247·44
March	252	247·05	243	246·63	251	247·63
April	276	247·35	268	246·93	276[1]	247·73
					301[2]	247·68
May	285	247·84	276	247·42	290	247·99
June	295	248·08	286	247·66	306	247·99
July	295	247·66	286	247·24	299	247·41
August	280	247·14	271	246·72	269	246·92
September	273	246·80	265	246·38	264	246·58
October	264	246·68	255	246·26	255	246·47
November	265	246·62	256	246·20	270	246·25
December	259	246·35	250	245·93	295[1]	245·84
					207[2]	245·98
1891—						
January	232	246·32	224	245·90	208	246·14
February	233	246·72	224	246·30	218	246·62
March	247	247·23	239	246·81	237	247·14
April	283	247·36	274	246·94	264[1]	247·26
					276[2]	247·31
May	279	247·04	270	246·62	271	247·09
June	268	246·69	260	246·27	259	246·75
July	266	246·33	257	245·91	247	246·51
August	255	245·90	247	245·48	241	246·15
September	245	245·36	236	244·94	234	245·64
October	230	244·74	221	244·32	222	245·02
November	222	244·42	213	244·00	213	244·71
December	221	244·46	212	244·04	197[1]	244·82
					198[2]	244·92
1892—						
January	202	244·50	193	244·08	199	244·90
February	187	244·54	178	244·12	201	244·65
March	190	244·90	182	244·48	199	244·80
April	231	245·22	222	244·80	199[1]	245·10
					200[2]	245·40
May	234	245·53	225	245·11	199	246·04

[1] First half of month. [2] Second half of month.

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1892—						
June	247	246·06	238	245·64	211	246·92
July	260	246·28	252	245·86	250	247·17
August	255	246·14	246	245·72	256	246·91
September	254	245·82	246	245·40	257	246·45
October	242	245·46	234	245·04	244	245·96
November	236	245·26	227	244·84	231	245·71
December	232	245·04	224	244·62	206[1]	245·71
					206[2]	245·71
1893—						
January	201	244·82	192	244·40	206	245·32
February	183	245·00	174	244·58	204	245·13
March	199	245·62	190	245·20	203	245·59
April	249	246·57	240	246·15	202[1]	246·30
					225[2]	246·88
May	275	247·26	266	246·84	244	247·86
June	282	247·24	274	246·82	297	247·55
July	277	246·84	268	246·42	277	247·04
August	262	246·44	254	246·02	257	246·60
September	259	246·04	250	245·62	248	246·22
October	247	245·58	239	245·16	238	245·77
November	238	245·30	230	244·68	228	245·52
December	233	245·39	225	244·97	204[1]	245·70
					206[2]	245·86
1894—						
January	218	245·65	209	245·23	207	246·15
February	197	245·89	188	245·47	218	246·01
March	230	246·06	222	245·64	217	246·23
April	251	246·18	243	245·76	227[1]	246·38
					234[2]	246·49
May	256	246·54	248	246·12	228	247·09
June	269	246·70	260	246·28	259	247·27
July	263	246·31	255	245·89	269	246·71
August	250	245·76	241	245·34	250	246·05
September	240	245·38	232	244·96	235	245·63
October	234	245·10	225	244·68	225	245·35
November	229	244·76	220	244·34	219	245·03
December	220	244·54	211	244·12	200[1]	244·99
					200[2]	244·95
1895—						
January	196	244·46	187	244·04	199	244·73
February	178	244·38	170	243·96	199	244·29
March	181	244·60	172	244·18	193	244·25
April	224	244·94	215	244·52	198[1]	244·53
					198[2]	244·81
May	229	244·94	220	244·52	198	245·09
June	226	244·74	218	244·32	196	245·17
July	220	244·46	211	244·04	195	245·09
August	217	244·17	208	243·75	205	244·71
September	208	243·83	200	243·41	203	244·32
October	200	243·54	192	243·12	202	243·77
November	194	243·42	185	243·00	191	243·58
December	194	243·62	185	243·20	188[1]	243·66
					189[2]	243·74
1896—						
January	187	244·03	179	243·61	182	244·10
February	188	244·38	180	243·96	189	244·34
March	185	244·95	177	244·53	194	244·70
April	233	245·42	225	245·00	191[1]	245·14
					192[2]	245·58
May	237	245·39	229	244·97	191	246·03

[1] First half of month. [2] Second half of month.

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1896—						
June	237	245·22	229	244·80	204	246·17
July	233	245·01	224	244·59	218	246·03
August	228	244·70	219	244·28	219	245·72
September	216	244·34	207	243·92	216	245·26
October	209	244·10	200	243·68	208	244·92
November	209	243·97	200	243·55	205	244·73
December	204	243·92	195	243·50	198[1]	244·68
					197[2]	244·64
1897—						
January	187	243·85	178	243·43	197	244·34
February	182	244·07	173	243·65	194	244·30
March	193	244·64	184	244·22	193	244·76
April	229	245·18	220	244·76	194[1]	245·20
					195[2]	245·64
May	239	245·50	231	245·08	198	246·36
June	245	245·61	236	245·19	225	246·61
July	242	245·60	233	245·18	240	246·52
August	242	245·35	233	244·93	240	246·18
September	228	244·78	220	244·36	235	245·42
October	215	244·44	207	244·02	217	244·94
November	211	244·44	203	244·02	211	244·84
December	215	244·56	207	244·14	198[1]	244·96
					199[2]	245·07
1898—						
January	201	244·86	193	244·44	200	245·28
February	210	245·28	201	244·86	204	245·67
March	223	245·70	214	245·28	209	246·16
April	244	246·00	235	245·58	219[1]	246·41
					231[2]	246·59
May	249	246·10	241	245·68	231	246·81
June	250	245·99	241	245·57	244	246·67
July	244	245·68	236	245·26	243	246·27
August	237	245·30	229	244·88	233	245·85
September	228	244·96	220	244·54	226	245·43
October	221	244·86	213	244·44	216	245·29
November	221	244·90	213	244·48	214	245·31
December	224	244·94	215	244·52	202[1]	245·41
					203[2]	245·51
1899—						
January	205	244·93	196	244·51	204	245·40
February	198	245·00	189	244·58	205	245·28
March	210	245·41	201	244·99	204	245·66
April	241	245·82	232	245·40	201[1]	246·06
					211[2]	246·40
May	247	246·00	238	245·58	216	246·86
June	251	246·00	243	245·58	244	246·85
July	246	245·69	238	245·27	250	246·39
August	234	245·20	226	244·78	239	245·74
September	224	244·75	216	244·33	226	245·16
October	215	244·48	207	244·06	216	244·77
November	213	244·39	205	243·97	212	244·59
December	215	244·50	207	244·08	196[1]	244·71
					197[2]	244·82
1900—						
January	199	244·76	193	244·48	198	245·02
February	199	245·04	194	244·76	202	245·20
March	204	245·50	198	245·22	203	245·50
April	242	245·90	236	245·62	200[1]	245·92
					208[2]	246·30
May	248	245·95	242	245·67	212	246·72

[1] First half of month. [2] Second half of month.

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1900—						
June	249	245·86	243	245·58	236	246·72
July	247	245·68	242	245·40	240	246·56
August	240	245·33	234	245·05	238	246·16
September	232	244·92	227	244·64	232	245·68
October	223	244·64	218	244·36	224	245·32
November	219	244·70	213	244·42	218	245·32
December	226	244·76	220	244·48	202[1]	245·47
					204[2]	245·59
1901—						
January	205	244·65	200	244·43	205	245·41
February	200	244·50	196	244·28	205	245·15
March	198	245·01	193	244·79	203	245·54
April	237	245·77	233	245·55	203[1]	246·12
					218[2]	246·60
May	246	245·95	242	245·73	233	246·89
June	249	245·86	245	245·64	249	246·75
July	244	245·58	239	245·36	247	246·37
August	237	245·26	233	245·04	238	245·98
September	231	244·88	227	244·66	233	244·52
October	223	244·46	219	244·24	221	244·07
November	213	244·32	208	244·10	216	244·83
December	216	244·39	212	244·17	198[1]	244·95
					199[2]	245·06
1902—						
January	197	244·36	193	244·15	200	244·95
February	177	244·62	172	244·41	201	244·85
March	208	245·18	204	244·97	200	245·45
April	237	244·44	232	245·23	199[1]	245·79
					204[2]	246·09
May	240	245·51	235	245·30	204	246·55
June	242	245·76	238	245·55	230	246·90
July	250	246·04	245	245·83	247	247·16
August	251	245·88	247	245·67	254	246·91
September	244	245·54	239	245·33	255	246·37
October	237	245·24	233	245·03	238	246·01
November	230	244·97	226	244·76	228	245·71
December	225	244·90	221	244·69	206[1]	245·76
					206[2]	245·81
1903—						
January	209	245·04	205	244·86	206	245·95
February	207	245·46	204	245·28	215	246·23
March	225	246·10	222	245·92	224	246·84
April	258	246·50	254	246·32	252[1]	247·05
					262[2]	247·20
May	261	246·50	257	246·32	260	247·16
June	257	246·52	254	246·34	256	247·16
July	260	246·47	257	246·29	257	247·11
August	256	246·21	253	246·03	253	246·85
September	251	245·90	248	245·72	251	246·63
October	240	245·54	236	245·36	251	246·08
November	227	245·24	224	245·06	236	245·63
December	220	244·92	216	244·76	205[1]	245·54
					204[2]	265·46
1904—						
January	192	244·86	188	244·66	204	245·20
February	196	245·32	192	245·12	203	245·52
March	207	246·32	203	246·12	207	246·47
April	255	247·30	251	247·10	235[1]	247·06
					263[2]	247·47

[1] First half of month. [2] Second half of month.

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1904—						
May	270	247·74	266	247·54	278	247·77
June	277	247·88	273	247·68	293	247·66
July	279	247·76	275	247·56	283	247·44
August	275	247·44	271	247·24	269	247·14
September	266	247·06	262	246·86	273	246·62
October	257	246·62	253	246·42	256	246·14
November	245	246·08	241	245·88	242	245·58
December	223	245·80	219	245·60	205[1]	245·53
					204[2]	245·48
1905—						
January	198	245·64	194	245·44	204	245·19
February	205	245·39	201	245·19	203	244·91
March	199	245·71	195	245·51	201	245·16
April	242	246·19	238	245·99	203[1]	245·61
					206[2]	246·05
May	244	246·42	240	246·22	210	246·65
June	251	246·78	247	246·58	242	247·07
July	260	246·94	256	246·74	263	247·15
August	259	246·82	255	246·62	262	246·95
September	256	246·60	252	246·40	264	246·59
October	250	246·26	246	246·06	255	246·14
November	243	245·98	239	245·78	242	245·83
December	237	246·00	233	245·80	206[1]	246·01
					216[2]	246·12
1906—						
January	229	246·11	225	245·89	209	246·42
February	221	246·00	217	245·78	222	246·24
March	218	246·08	214	245·86	225	246·18
April	243	246·32	238	246·10	225[1]	246·38
					238[2]	246·50
May	247	246·40	243	246·18	232	246·71
June	249	246·49	245	246·27	246	246·79
July	252	246·42	247	246·20	253	246·65
August	245	246·04	240	245·82	249	246·16
September	236	245·64	232	245·42	239	245·67
October	233	245·53	229	245·31	227	245·58
November	231	245·66	227	245·44	224	245·74
December	229	246·04	225	245·82	206[1]	246·04
					216[2]	246·29
1907—						
January	212	246·40	209	246·23	210	246·63
February	218	246·46	215	246·29	224	246·53
March	224	246·66	220	246·49	235	246·54
April	256	246·96	253	246·79	242[1]	246·76
					255[2]	246·90
May	262	247·10	259	246·93	251	247·14
June	263	247·12	260	246·95	262	247·14
July	265	247·01	261	246·84	264	246·99
August	260	246·70	257	246·53	259	246·65
September	251	246·49	247	246·32	252	246·37
October	249	246·40	246	246·23	247	246·26
November	247	246·33	243	246·16	248	246·14
December	247	246·53	243	246·36	267[1]	246·09
					216[2]	246·37
1908—						
January	221	246·86	217	246·70	211	246·78
February	218	247·19	214	247·03	226	246·97
March	223	247·71	220	247·55	243	247·32
April	281	248·24	277	248·08	269[1]	247·64
					296[2]	247·79

[1] First half of month. [2] Second half of month.

TABLE19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month (a)	Unregulated with actual diversions (from records) Discharge 1,000's of c.f.s. (b)	Elevation Ontario (Oswego) end of month (c)	Unregulated with continuous diversion of 8,500 c.f.s. Discharge 1,000's of c.f.s. (d)	Elevation Ontario end of month (e)	Regulated with diversion of 8,500 c.f.s. Discharge 1,000's of c.f.s. (f)	Elevation Ontario end of period (g)
1908—						
May	292	248·54	289	248·38	296	248·00
June	294	248·48	291	248·32	309	247·71
July	289	248·14	286	247·98	287	247·36
August	279	247·55	276	247·39	269	246·86
September	264	246·79	260	246·63	261	246·10
October	249	246·18	245	246·02	238	245·59
November	239	245·72	236	245·56	225	245·27
December	230	245·34	227	245·18	202[1]	245·25
					202[2]	245·23
1909—						
January	203	245·23	201	245·09	202	245·11
February	197	245·49	194	245·35	203	245·26
March	211	245·94	208	245·80	204	245·76
April	243	246·67	240	246·53	206[1]	246·34
					229[2]	246·76
May	262	247·23	259	247·09	237	247·60
June	267	247·23	264	247·09	283	247·36
July	264	246·99	262	246·85	269	247·02
August	257	246·55	254	246·41	255	246·57
September	245	246·06	242	245·92	245	246·05
October	237	245·60	235	245·46	233	245·61
November	225	245·28	222	245·14	221	245·30
December	224	245·08	221	244·94	202[1]	245·32
					202[2]	245·34
1910—						
January	198	244·98	195	244·85	203	245·14
February	188	245·39	186	245·26	203	245·34
March	214	245·86	212	245·73	205	245·89
April	238	246·20	235	246·07	209[1]	246·21
					222[2]	246·46
May	249	246·44	246	246·31	221	247·01
June	250	246·37	247	246·24	250	246·91
July	247	246·17	244	246·04	249	246·65
August	243	245·88	241	245·75	238	246·39
September	232	245·54	230	245·41	234	246·00
October	227	245·26	224	245·13	226	245·70
November	221	245·02	218	244·89	220	245·44
December	216	244·83	214	244·70	203[1]	245·42
					203[2]	245·40
1911—						
January	194	244·81	192	244·70	203	245·24
February	191	244·91	188	244·80	204	245·14
March	197	245·20	194	245·09	203	245·33
April	225	245·52	223	245·41	194[1]	245·67
					198[2]	245·98
May	232	245·63	230	245·52	196	246·52
June	233	245·60	231	245·49	224	246·57
July	232	245·36	230	245·25	231	246·32
August	224	245·03	221	244·92	226	245·93
September	215	244·75	213	244·64	219	245·57
October	212	244·56	210	244·45	209	245·38
November	213	244·56	210	244·45	208	245·40
December	214	244·69	211	244·58	203[1]	245·52
					204[2]	245·63
1912—						
January	192	244·81	191	244·74	205	245·58
February	181	244·98	180	244·91	207	245·40
March	189	245·71	187	245·64	205	245·91
April	237	246·57	235	246·50	202[1]	246·55
					231[2]	247·00

[1] First half of month. [2] Second half of month.

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1912—						
May	254	247·08	253	247·01	242	247·65
June	269	247·17	267	247·10	276	247·63
July	259	246·83	258	246·76	272	247·12
August	253	246·52	252	246·45	249	246·84
September	248	246·27	246	246·20	249	246·55
October	244	246·12	243	246·05	245	246·37
November	242	246·09	241	246·02	252	246·21
December	244	246·31	242	246·24	292[1]	246·01
					216[2]	246·29
1913—						
January	232	246·63	230	246·56	210	246·87
February	239	246·73	238	246·66	227	246·98
March	234	247·28	232	247·21	244	247·38
April	273	247·91	271	247·84	267[1]	247·73
					295[2]	247·91
May	278	248·00	277	247·93	300	247·71
June	281	247·92	279	247·85	291	247·49
July	278	247·57	277	247·50	274	277·18
August	266	247·02	265	246·95	259	246·70
September	253	246·51	252	246·44	250	246·21
October	244	246·17	242	246·10	237	245·93
November	243	245·98	241	245·91	231	245·87
December	240	245·75	238	245·68	207[1]	245·95
					212[2]	246·00
1914—						
January	214	245·73	213	245·66	208	246·04
February	202	245·77	201	245·70	217	245·88
March	203	246·21	202	246·14	214	246·17
April	250	246·85	248	246·78	220[1]	246·67
					243[2]	247·02
May	257	246·93	256	246·86	249	247·18
June	257	246·81	255	246·74	256	247·04
July	253	246·52	251	246·45	253	246·73
August	246	246·21	244	246·14	243	246·44
September	241	245·84	240	245·77	237	246·12
October	230	245·42	229	245·35	231	245·68
November	227	245·04	226	244·96	221	245·37
December	216	244·76	215	244·69	203[1]	245·29
					202[2]	245·23
1915—						
January	199	244·84	198	244·80	202	245·25
February	191	245·13	190	245·09	204	245·37
March	208	245·15	207	245·11	205	245·41
April	222	245·09	221	245·05	196[1]	245·53
					198[2]	145·64
May	222	245·13	221	245·09	194	246·02
June	221	245·12	219	245·08	203	246·22
July	222	245·28	221	245·24	217	246·43
August	228	245·44	227	245·40	227	246·58
September	229	245·31	228	245·27	236	246·36
October	225	245·05	224	245·01	231	246·02
November	219	244·86	218	244·82	224	245·76
December	213	244·91	212	244·87	206[1]	245·82
					206[2]	245·88
1916—						
January	205	245·23	204	245·19	207	246·16
February	204	245·43	203	245·39	219	246·16
March	201	245·93	200	245·89	222	246·38
April	246	246·76	245	246·72	225[1]	246·92
					250[2]	247·30

[1] First half of month. [2] Second half of month.

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1916—						
May	262	247·49	262	247·45	262	248·02
June	276	247·89	275	247·85	300	248·11
July	278	247·64	277	247·60	298	247·60
August	267	247·02	266	246·98	268	246·96
September	254	246·37	253	246·33	259	246·24
October	241	245·85	240	245·61	238	245·75
November	231	245·51	230	245·47	226	245·46
December	224	245·31	223	245·27	204[1]	245·48
					204[2]	245·50
1917—						
January	204	245·17	203	245·13	204	245·35
February	205	245·12	205	245·08	205	245·30
March	207	245·70	207	245·66	204	245·91
April	243	246·38	242	246·34	213[1]	246·43
					236[2]	246·81
May	246	246·75	245	246·71	245	247·17
June	258	247·22	257	247·18	264	247·56
July	269	247·40	268	247·36	280	247·60
August	269	247·14	268	247·10	276	247·24
September	258	246·80	258	246·76	281	246·60
October	254	246·68	253	246·64	257	246·42
November	251	246·57	250	246·53	266	246·12
December	246	246·26	245	246·22	259[1]	245·87
					207[2]	245·95
1918—						
January	217	246·03	216	245·98	208	245·83
February	212	246·30	211	245·25	212	246·09
March	228	246·89	227	245·84	220	246·77
April	259	247·15	258	247·10	253[1]	246·93
					267[2]	247·01
May	261	247·07	260	247·02	262	246·91
June	260	246·93	259	246·88	258	246·79
July	258	246·64	257	246·59	259	246·48
August	249	246·32	248	246·27	249	246·16
September	244	246·10	243	246·05	242	245·95
October	238	246·00	237	245·95	238	245·84
November	240	245·95	239	245·90	233	245·86
December	236	245·99	235	245·94	207[1]	246·06
					216[2]	246·20
1919—						
January	226	246·00	225	245·96	210	246·40
February	222	245·96	221	245·92	222	246·35
March	226	246·22	225	246·18	228	246·57
April	252	246·85	251	246·81	244[1]	246·92
					262[2]	247·17
May	269	247·61	268	247·57	266	247·96
June	279	247·85	278	247·81	306	247·85
July	275	247·54	274	247·50	290	247·35
August	267	247·10	266	247·06	263	246·95
September	256	246·60	255	246·56	260	246·39
October	246	246·23	246	246·19	241	246·08
November	241	245·92	240	245·88	234	245·84
December	236	245·53	235	245·49	207[1]	245·82
					206[2]	245·81
1920—						
January	201	245·16	201	245·16	206	245·39
February	192	245·03	192	245·03	205	245·09
March	197	245·30	197	245·30	203	245·29
April	232	245·57	232	245·57	200[1]	245·63
					203[2]	245·95

[1] First half of month. [2] Second half of month.

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Continued*

Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1920—						
May	231	245·58	231	245·58	206	246·26
June	230	245·63	230	245·63	224	246·38
July	234	245·66	234	245·66	233	246·42
August	231	245·55	231	245·55	238	246·22
September	229	245·38	229	245·38	236	245·96
October	226	245·26	226	245·26	230	245·80
November	220	245·32	220	245·32	226	245·79
December	227	245·47	227	245·47	206[1]	245·99
					215[2]	246·14
1921—						
January	215	245·50	215	245·50	209	246·24
February	210	245·62	210	245·62	220	246·23
March	222	246·09	222	246·09	224	246·67
April	247	246·53	247	246·53	242[1]	246·92
					254[2]	247·10
May	253	246·65	253	246·65	254	247·20
June	252	246·49	252	246·49	259	246·95
July	247	246·15	247	246·15	249	246·59
August	238	245·68	238	245·68	236	246·15
September	228	245·27	228	245·27	228	245·74
October	221	244·98	221	244·98	218	245·48
November	210	244·84	210	244·84	212	245·32
December	215	244·78	215	244·78	202[1]	245·37
					203[2]	245·42
1922—						
January	197	244·72	197	244·72	203	245·28
February	188	244·89	188	244·89	204	245·24
March	202	245·57	202	245·57	204	245·89
April	244	246·30	244	246·30	203[1]	246·51
					230[2]	246·96
May	250	246·65	250	246·65	244	247·38
June	253	246·83	253	246·83	266	247·39
July	258	246·74	258	246·74	265	247·21
August	250	246·30	250	246·30	253	246·73
September	239	245·82	239	245·82	244	246·19
October	233	245·38	233	245·38	232	245·77
November	220	244·89	220	244·89	220	245·28
December	210	244·57	210	244·57	202[1]	245·17
					201[2]	245·07
1923—						
January	190	244·48	190	244·48	200	244·86
February	188	244·60	188	244·60	201	244·81
March	199	245·04	199	245·04	200	245·11
April	227	245·47	227	245·47	189[1]	245·56
					191[2]	246·00
May	230	245·78	230	245·78	194	246·76
June	236	245·86	236	245·86	231	246·91
July	232	245·60	232	245·60	242	246·52
August	226	245·22	226	245·22	229	246·10
September	217	244·84	217	244·84	222	245·66
October	208	244·50	208	244·50	211	245·28
November	203	244·40	203	244·40	205	245·16
December	206	244·62	206	244·62	201[1]	245·31
					202[2]	245·45
1924—						
January	198	244·81	198	244·81	203	245·59
February	192	244·86	192	244·86	208	245·44
March	196	245·12	196	245·12	206	245·56
April	224	245·73	224	245·73	189[1]	246·08
					202[2]	246·52

[1] First half of month. [2] Second half of month.

TABLE 19.—EFFECT OF PROPOSED PROGRAM FOR REGULATION OF LAKE ONTARIO ALONE—*Concluded*

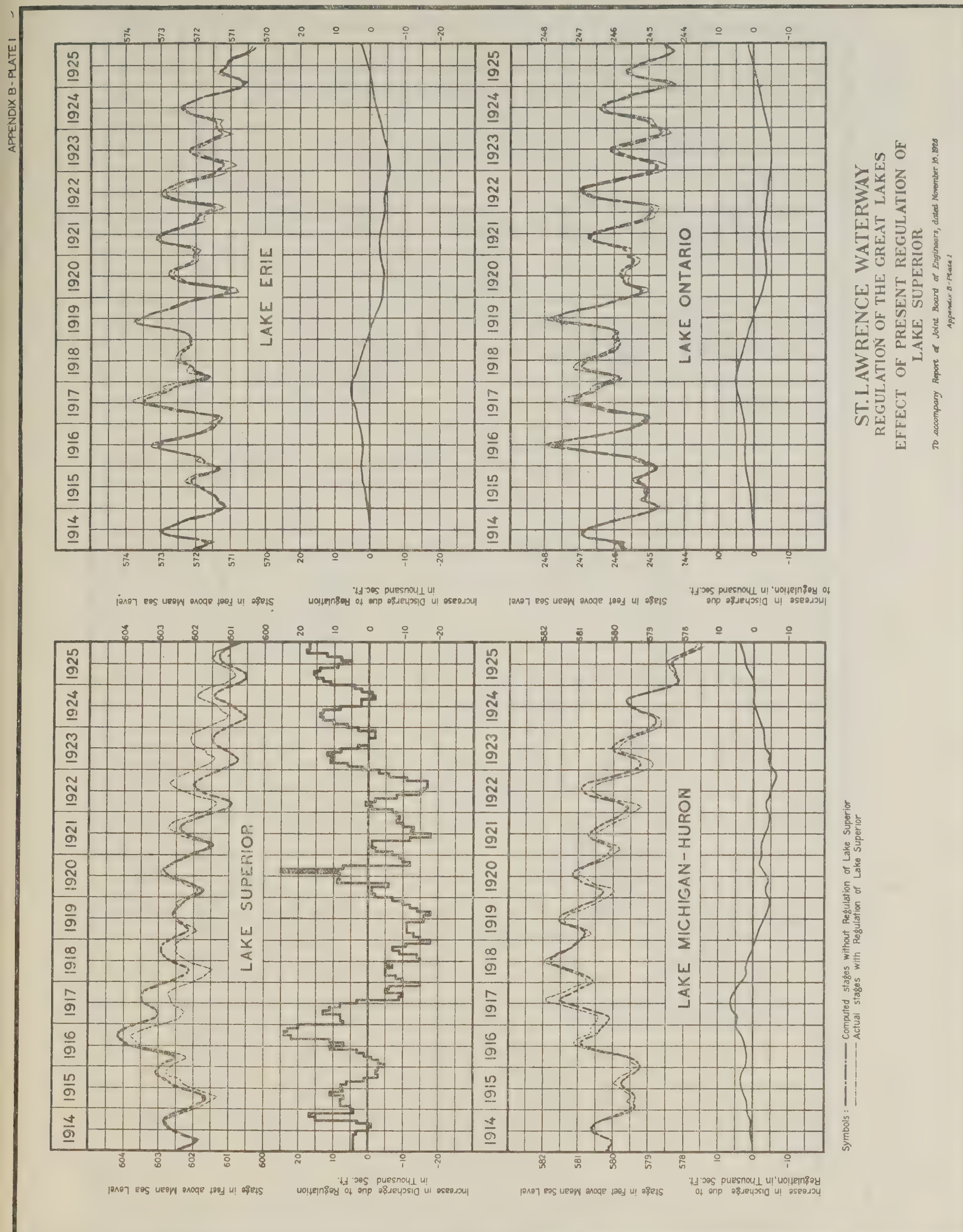
Year and Month	Unregulated with actual diversions (from records)		Unregulated with continuous diversion of 8,500 c.f.s.		Regulated with diversion of 8,500 c.f.s.	
	Discharge 1,000's of c.f.s.	Elevation Ontario (Oswego) end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of month	Discharge 1,000's of c.f.s.	Elevation Ontario end of period
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1924—						
May	239	246·18	239	246·18	210	247·33
June	242	246·24	242	246·24	253	247·25
July	242	246·12	242	246·12	248	247·05
August	239	245·83	239	245·83	238	246·77
September	230	245·55	230	245·55	237	246·41
October	225	245·20	225	245·20	229	246·01
November	218	244·77	218	244·77	217	245·60
December	208	244·40	208	244·40	205[1]	245·44
					203[2]	245·29
1925—						
January	169	244·32	169	244·32	202	244·80
February	176	244·80	176	244·80	200	244·99
March	201	245·40	201	245·40	202	245·58
April	226	245·62	226	245·62	186[1]	245·93
					194[2]	246·23
May	228	245·53	228	245·53	191	246·61
June	225	245·32	225	245·32	214	246·53
July	220	245·05	220	245·05	215	246·33
August	215	244·73	215	244·73	211	246·07
September	207	244·44	207	244·44	208	245·77
October	201	244·32	201	244·32	201	245·65
November	205	244·43	205	244·43	197	245·86
December	208	244·42	208	244·42	207[1]	245·86
					207[2]	245·86

[1] First half of month. [2] Second half of month.

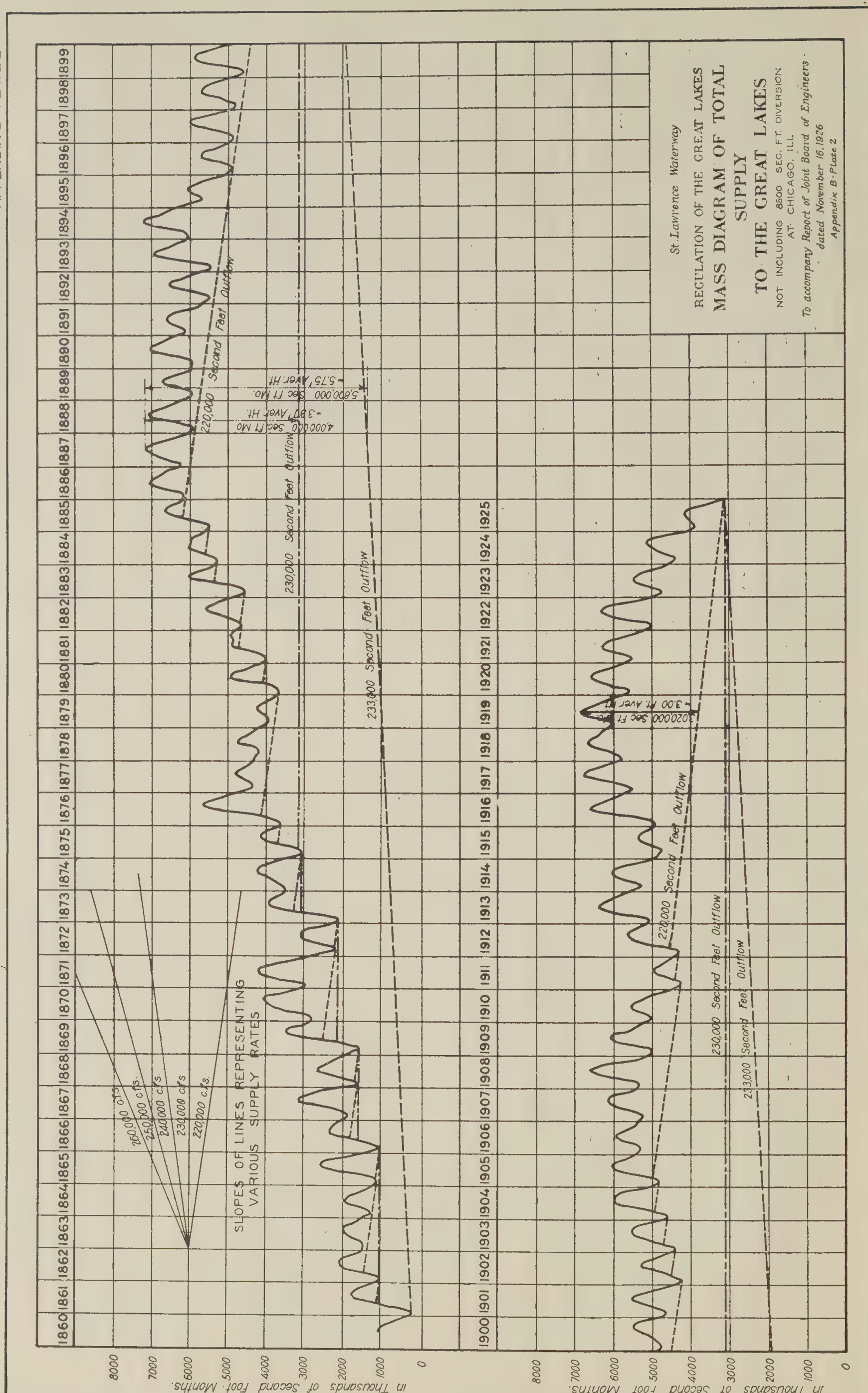
TABLE 20.—DETAILS OF COST OF WORKS FOR REGULATION WITH COMPLETE CONTROL OF ST. CLAIR RIVER

Control	Structure	Item	Quantity	Unit	Unit price	Cost
					$ cts.	$
Pt. Edward Bypass	Canal	Excavation	7,800,000	cu. yd.	0 20	1,560,000
		Property damage				150,000
		Railroad changes				50,000
	Regulating works					650,000
						2,410,000
		Engineering and contingencies	15−%			360,000
						2,770,000
Stag Island	Regulating works	Concrete	21,500	cu. yd.	15 00	322,500
		Riprap	5,050	"	3 00	15,150
		Piles	72,000	lin ft.	0 85	61,200
		Cofferdam and pumping	2,500	"	240 00	600,000
		Gates and superstructure	2,045,000	lbs.	0 08	163,600
		Operating machinery				30,000
	Longitudinal dike	Rock (low dike)	134,000	cu. yd.	2 50	335,000
		High dike	17,200	lin. ft.	175 00	3,010,000
		"	12,200	"	210 00	2,562,000
	Channel protection	Riprap	850,000	cu. yd.	2 00	1,700,000
						8,799,450
		Engineering and contingencies	15+%			1,320,550
						10,120,000
Woodtick Island	Regulating works	Concrete	25,500	cu. yd.	15 00	382,500
		Riprap	6,000	"	3 00	18,000
		Gates and superstructure	1,175,000	lbs.	0 08	94,000
		Operating machinery				40,000
		Piling	73,000	lin. ft.	0 85	62,050
		Cofferdam and pumping	3,000	"	210 00	630,000
		Dredging	150,000	cu. yd.	0 50	75,000
	Longitudinal dike	High dike	12,300	lin. ft.	128 00	1,574,400
	Channel protection	Riprap	183,000	cu. yd.	2 00	366,000
						3,241,950
		Engineering and contingencies	15+%			488,050
						3,730,000
St. Clair Delta Control	Regulating works	Materials				593,000
		Excavation	4,400,000	cu. yd.	0 25	1,100,000
		Property damage				80,000
	Channel straightening	Excavation	11,200,000	"	0 25	2,800,000
		Land damage				81,000
	Connection with middle and north channels	Excavation	1,020,000	"	0 25	255,000
	Channel protection	Riprap	220 000	"	2 00	440,000
						5,349,000
		Engineering and contingencies	15−%			801,000
						6,150,000
Niagara River	Longitudinal dike	Crib dike	4,000	lin. ft.	160 00	640,000
	Cofferdam	"	4,000	"	160 00	640,000
		Pumping				100,000
	Channel enlargement	Dry rock excavation	3,450,000	cu. yd.	1 75	6,038,000
		Wet rock eacavation	850,000	"	4 00	3,400,000
	Waterworks intake	Relocation				60,000
	Regulating works					990,000
						11,868,000
		Engineering and contingencies	15+%			1,782,000
						13,650,000
Total Cost for Complete Control						36,420,000

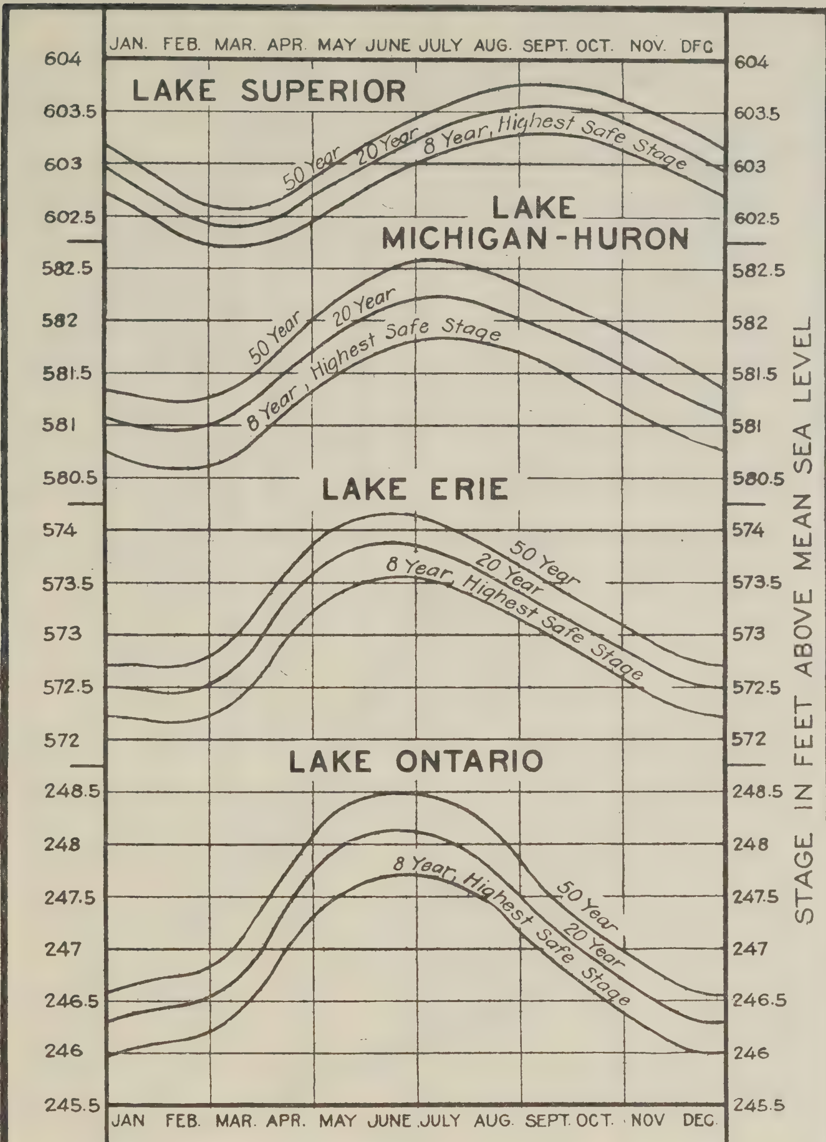
Detroit River—Not used	Control works west of Grosse Isle	$ 839,000
	Control works east of Fighting Island	1,070,000
	Longitudinal dike on bar near upper end of Grosse Isle	1,020,000
	Control works, Grosse Isle to longitudinal dike	766,000
		$ 3,695,000
	Engineering and contingencies 15+%	555,000
		$ 4,250,000


APPENDIX B - PLATE I
LAKE SUPERIOR
LAKE MICHIGAN-HURON
LAKE ERIE
LAKE ONTARIO
Stage in Feet above Mean Sea Level
Increase in Discharge due to Regulation in Thousand Sec. Ft.
Symbols: Computed stages without Regulation of Lake Superior
Actual stages with Regulation of Lake Superior
ST. LAWRENCE WATERWAY
REGULATION OF THE GREAT LAKES
EFFECT OF PRESENT REGULATION OF
LAKE SUPERIOR
Appendix B-Plate I

APPENDIX B - PLATE 2



APPENDIX B - PLATE 3



St. Lawrence Waterway

REGULATION OF THE GREAT LAKES

STAGES IN ALL LAKES WITH PROBABLE FREQUENCY

of once in

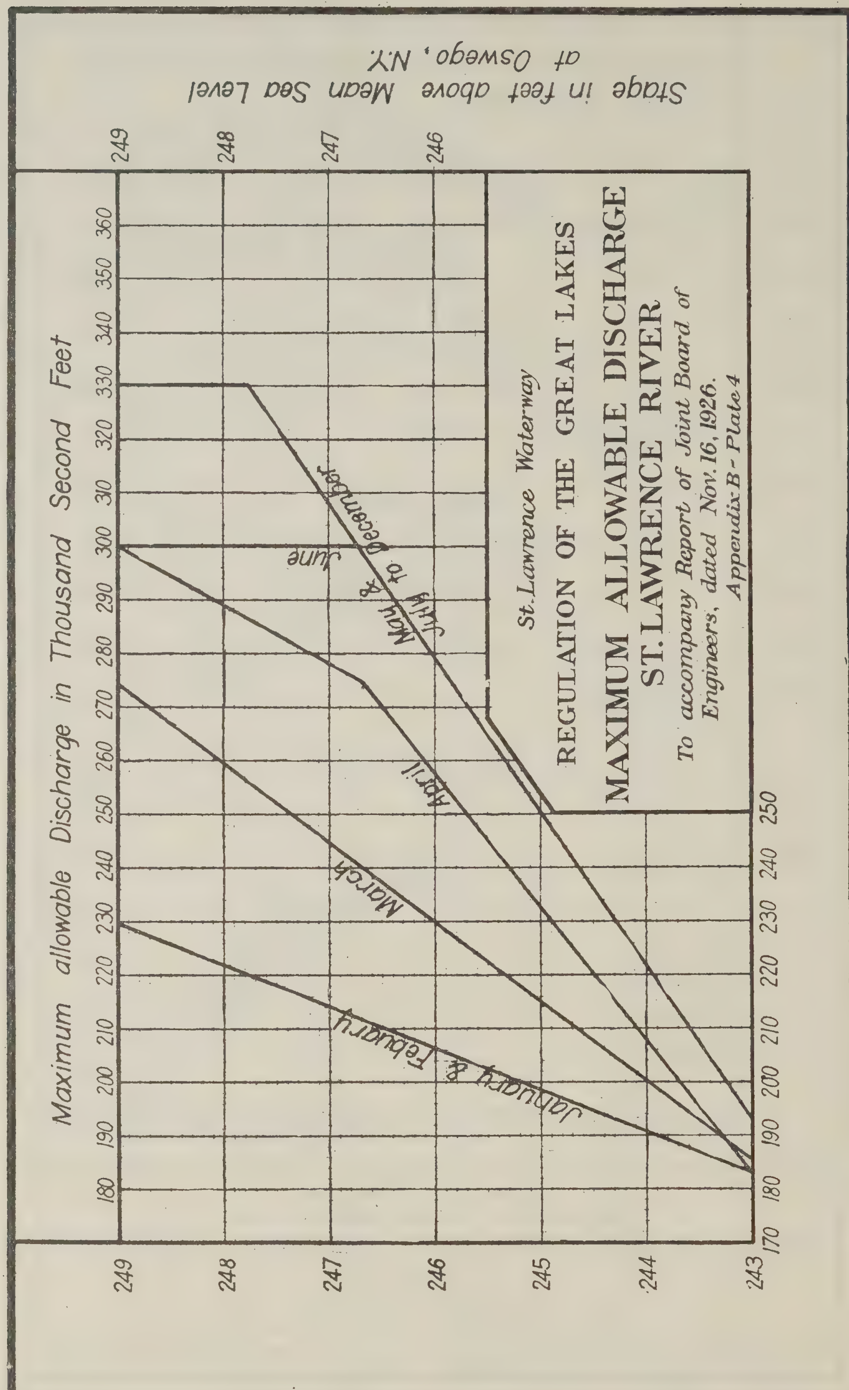
8, 20 and 50 Years

Based on 1901-1925 Records

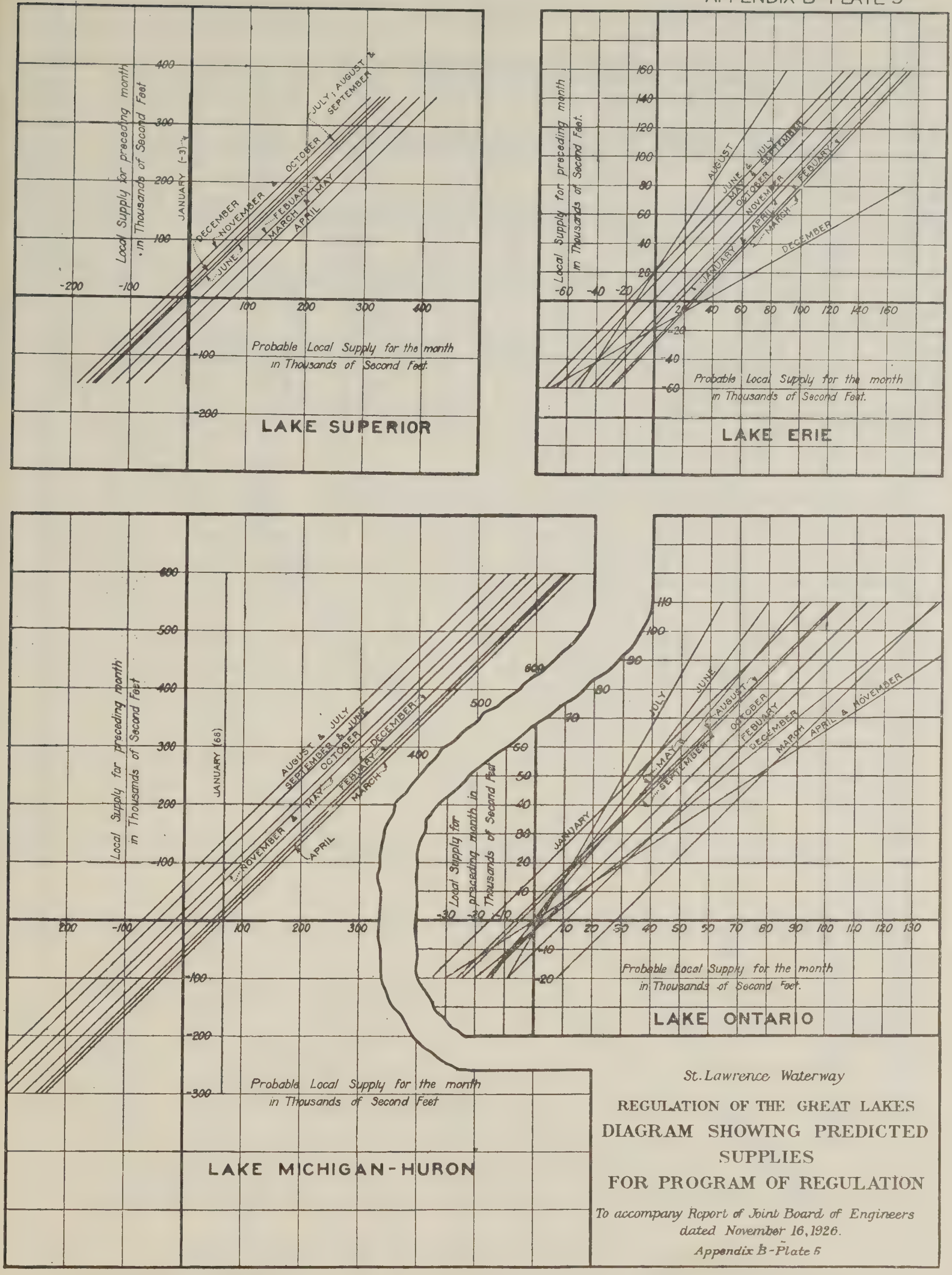
To accompany Report of Joint Board of Engineers, dated Nov. 16, 1926

Appendix B - Plate 3

APPENDIX B - PLATE 4



APPENDIX B - PLATE 5



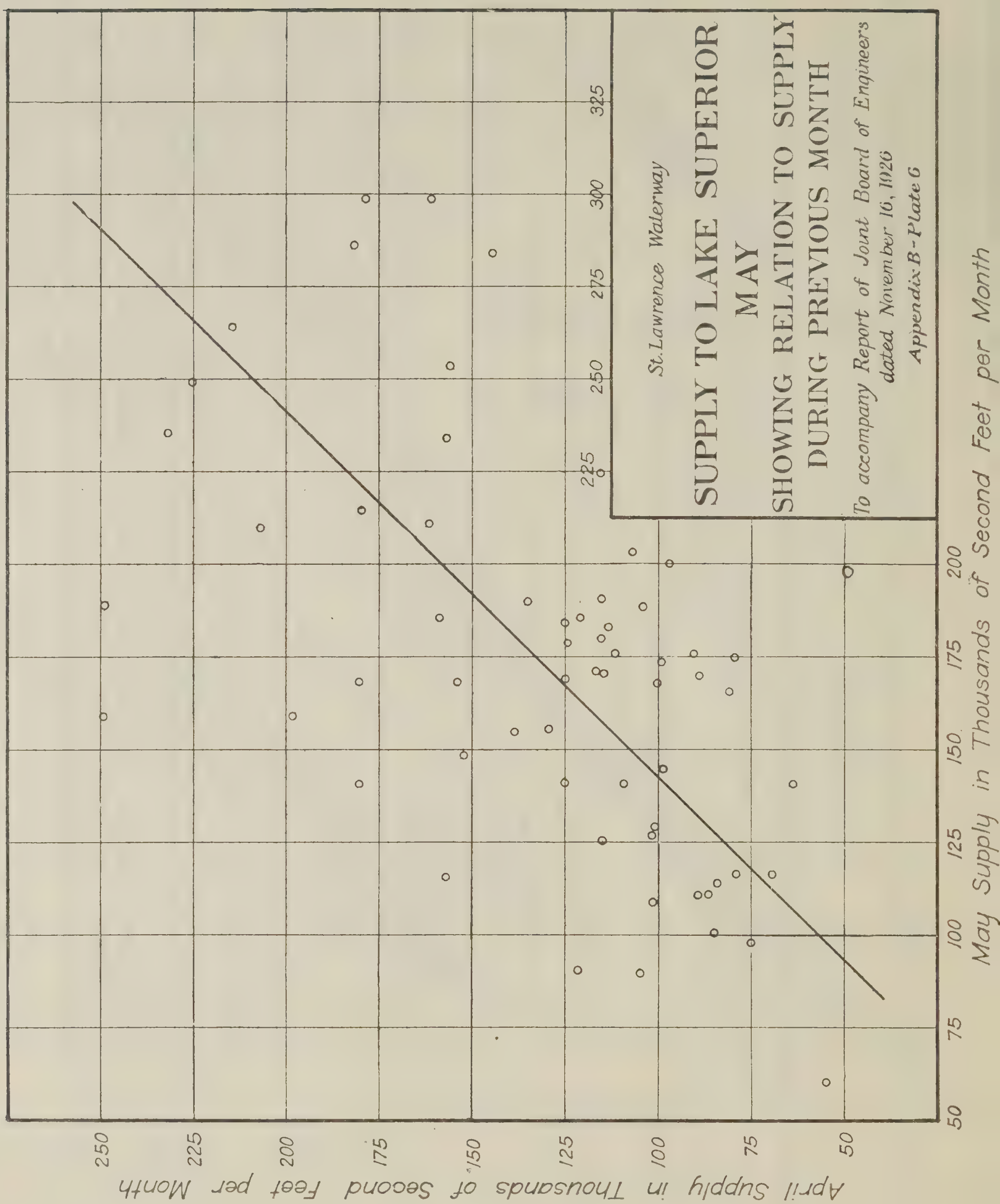
St. Lawrence Waterway

REGULATION OF THE GREAT LAKES
DIAGRAM SHOWING PREDICTED SUPPLIES
FOR PROGRAM OF REGULATION

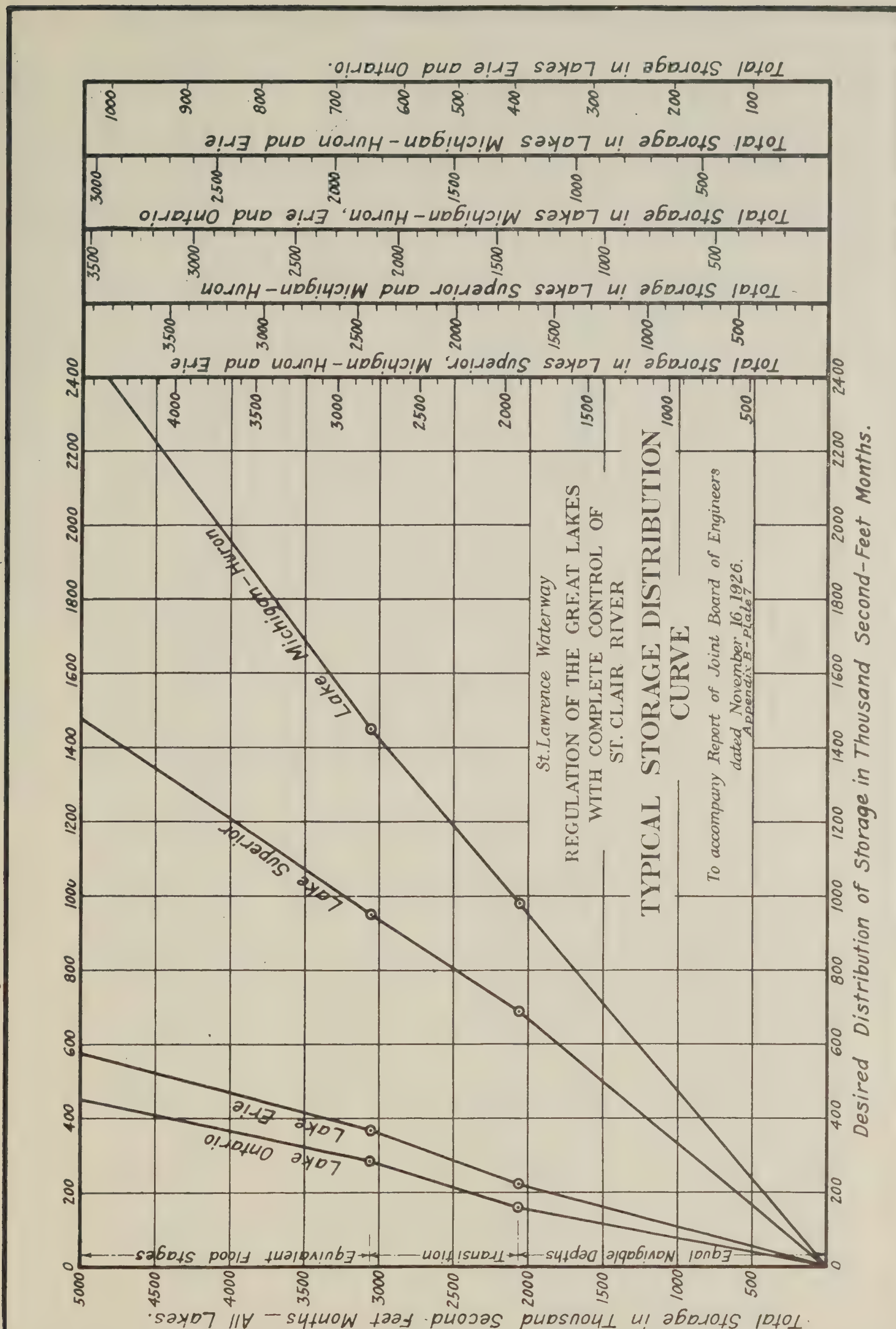
To accompany Report of Joint Board of Engineers dated November 16, 1926.

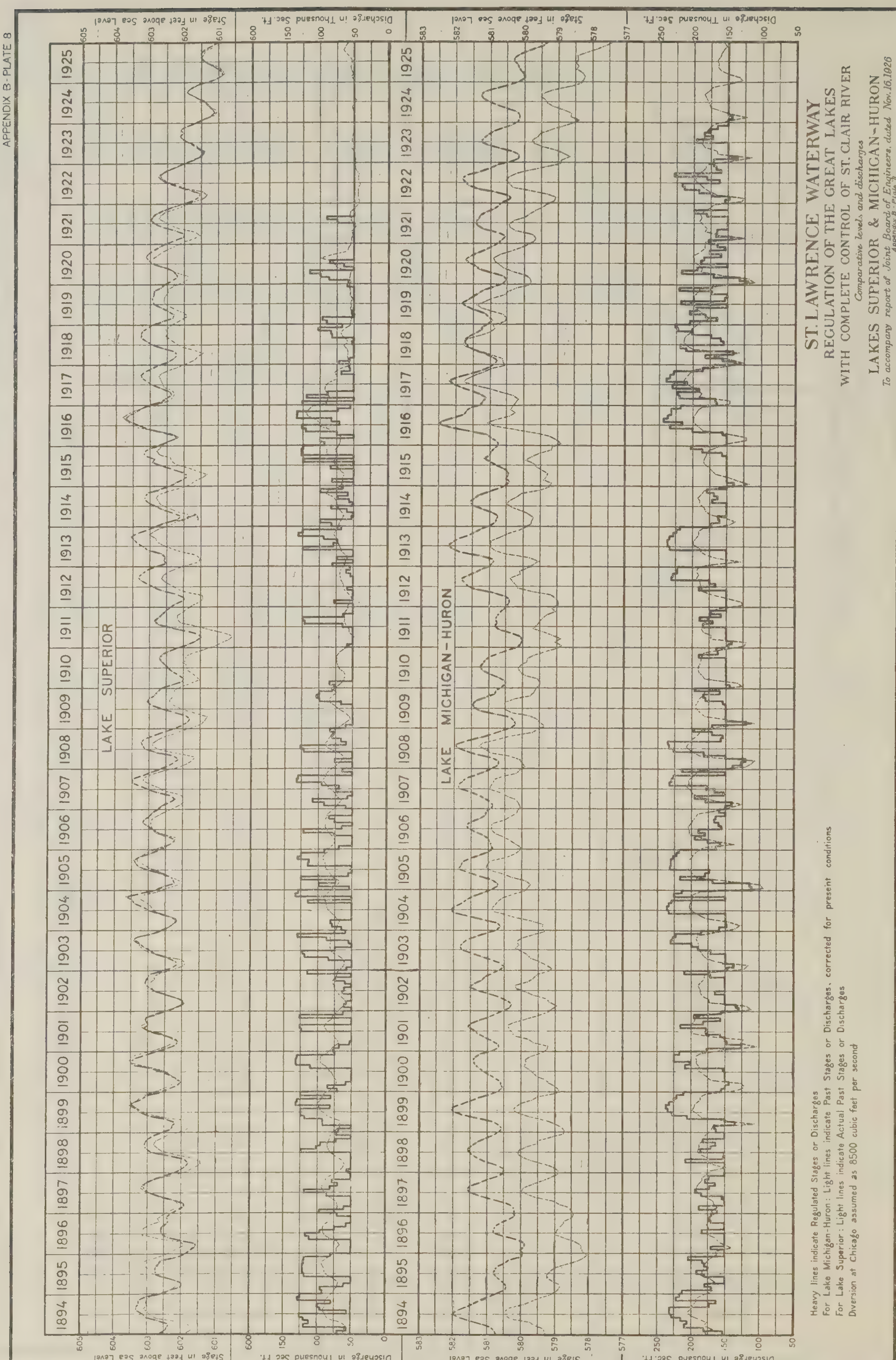
Appendix B - Plate 5

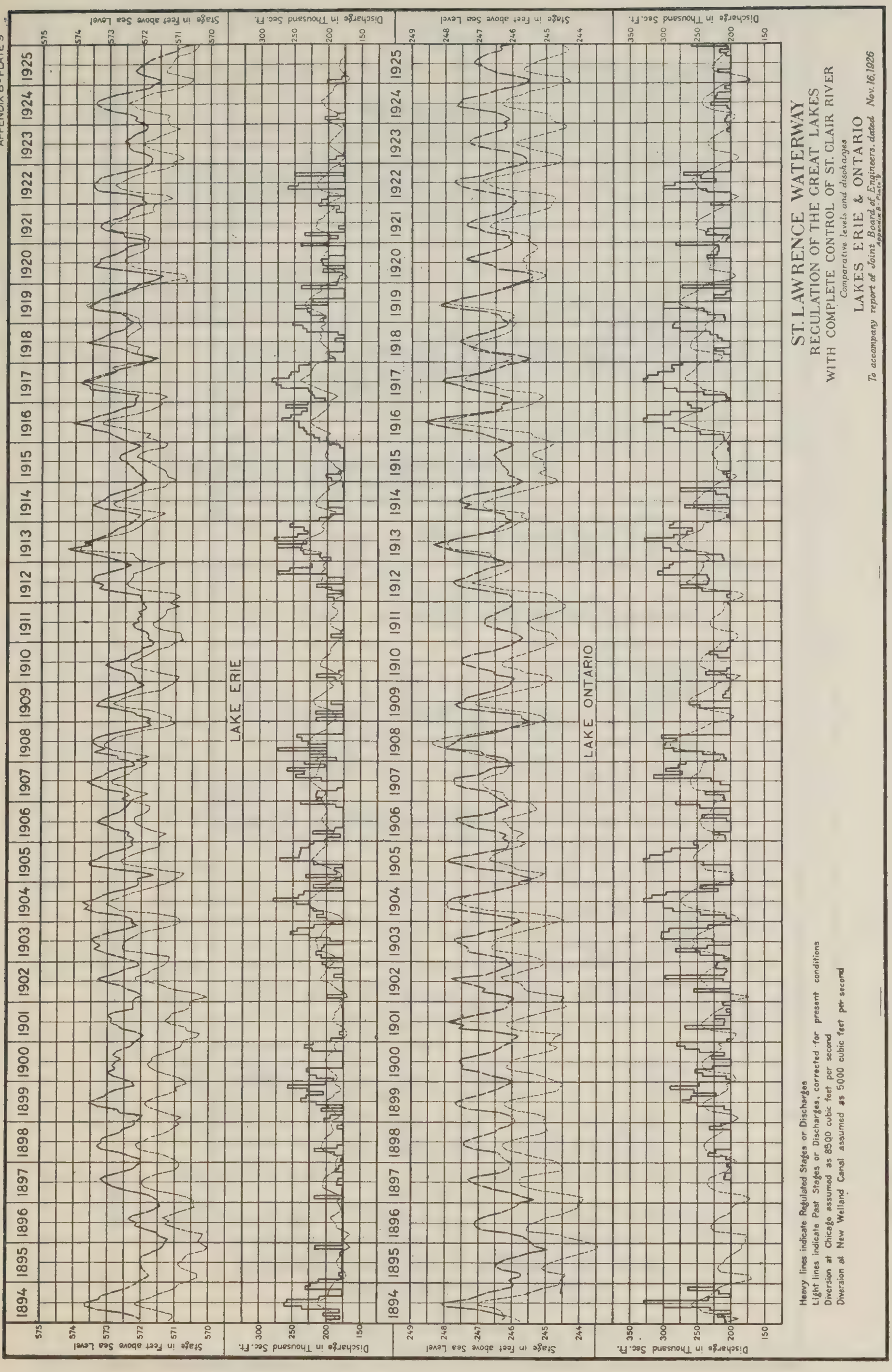
APPENDIX B - PLATE 6



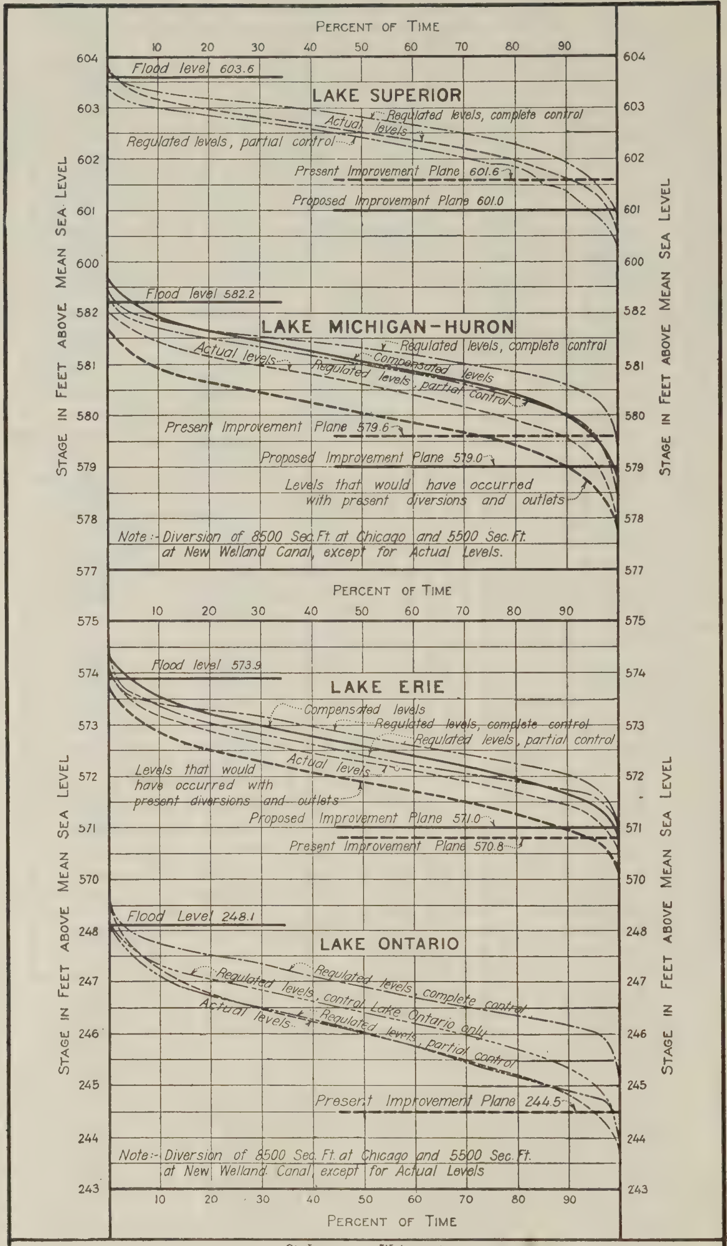
APPENDIX B - PLATE 7




APPENDIX B - PLATE 8
ST. LAWRENCE WATERWAY
REGULATION OF THE GREAT LAKES
WITH COMPLETE CONTROL OF ST. CLAIR RIVER
Comparative levels and discharges
LAKES SUPERIOR & MICHIGAN-HURON
To accompany report of Joint Board of Engineers, dated Nov. 16, 1926
LAKE SUPERIOR
LAKE MICHIGAN-HURON
Stage in Feet above Sea Level
Discharge in Thousand Sec. Ft.
Heavy lines indicate Regulated Stages or Discharges
For Lake Michigan-Huron: Light lines indicate Past Stages or Discharges, corrected for present conditions
For Lake Superior: Light lines indicate Actual Past Stages or Discharges
Diversion at Chicago assumed as 8500 cubic feet per second


APPENDIX B - PLATE 9
ST. LAWRENCE WATERWAY
REGULATION OF THE GREAT LAKES
WITH COMPLETE CONTROL OF ST. CLAIR RIVER
Comparative levels and discharges
LAKES ERIE & ONTARIO
To accompany report of Joint Board of Engineers, dated Nov. 16, 1926
Heavy lines indicate Regulated Stages or Discharges
Light lines indicate Past Stages or Discharges, corrected for present conditions
Diversion at Chicago assumed as 8500 cubic feet per second
Diversion at New Welland Canal assumed as 5000 cubic feet per second
LAKE ERIE
LAKE ONTARIO
Stage in Feet above Sea Level
Discharge in Thousand Sec. Ft.
1894 1895 1896 1897 1898 1899 1900 1901 1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913 1914 1915 1916 1917 1918 1919 1920 1921 1922 1923 1924 1925
575 574 573 572 571 570
300 250 200 150
249 248 247 246 245 244
350 300 250 200 150

APPENDIX B PLATE 10



St. Lawrence Waterway

REGULATION OF THE GREAT LAKES

STAGE DURATION CURVE OF VARIOUS SCHEMES OF REGULATION

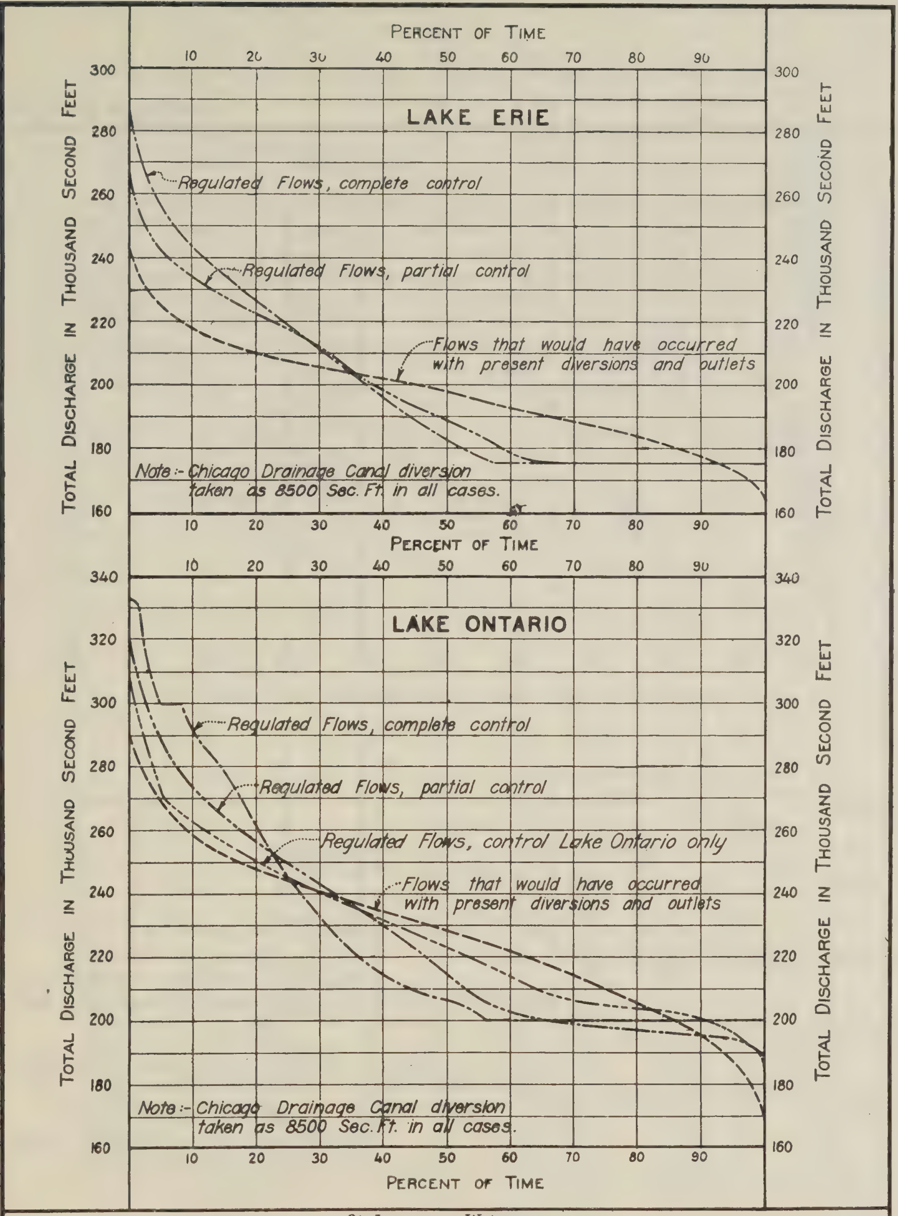
PERIOD 1894 - 1925

NAVIGATION SEASON APRIL 1, TO DECEMBER 1.

To accompany Report of Joint Board of Engineers dated Nov. 16, 1926

Appendix B - Plate 10

APPENDIX B - PLATE 11



St. Lawrence Waterway

REGULATION OF THE GREAT LAKES

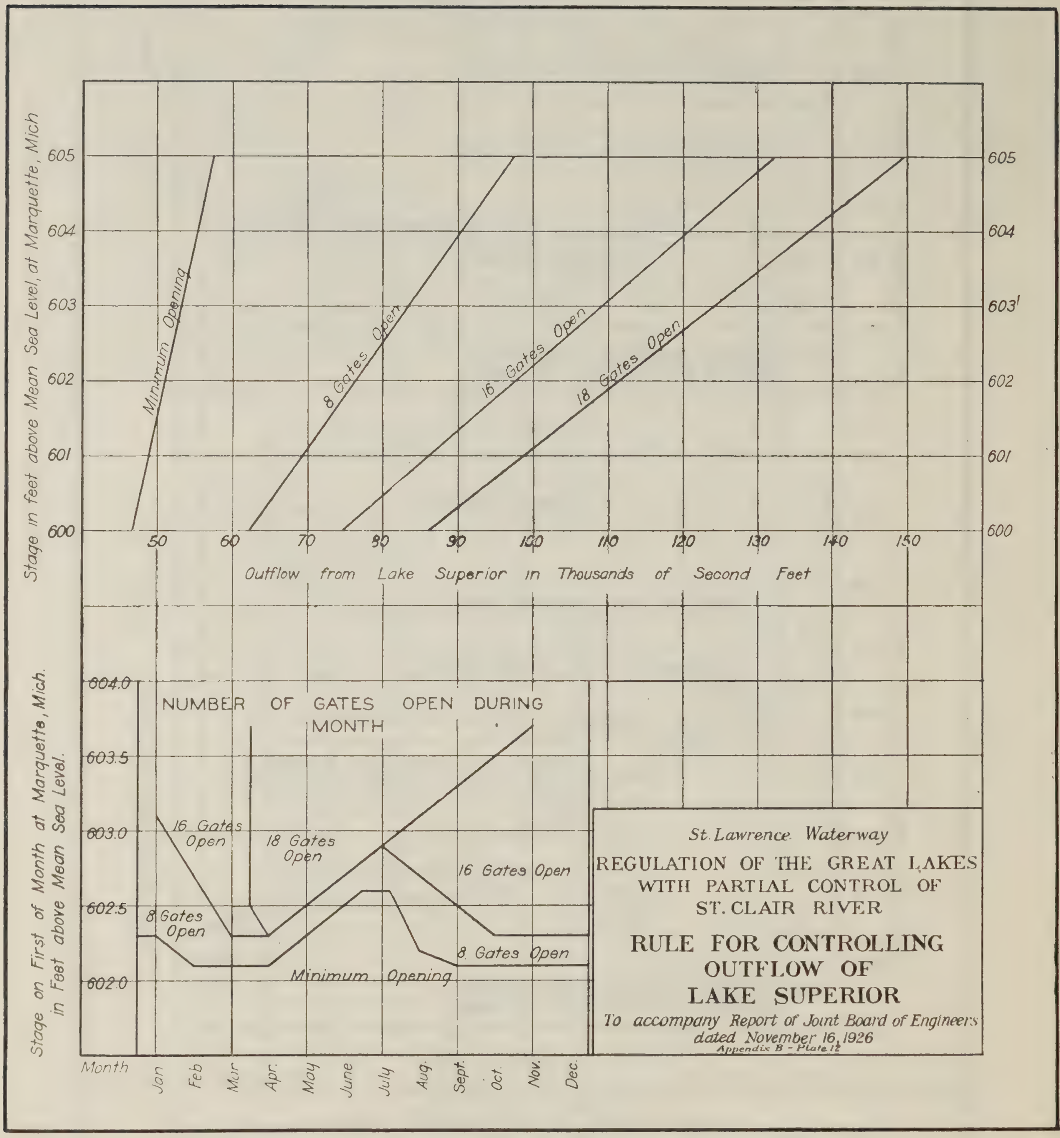
DISCHARGE DURATION CURVE OF VARIOUS SCHEMES OF REGULATION

PERIOD 1894 - 1925

To accompany Report of Joint Board of Engineers dated Nov. 16, 1926

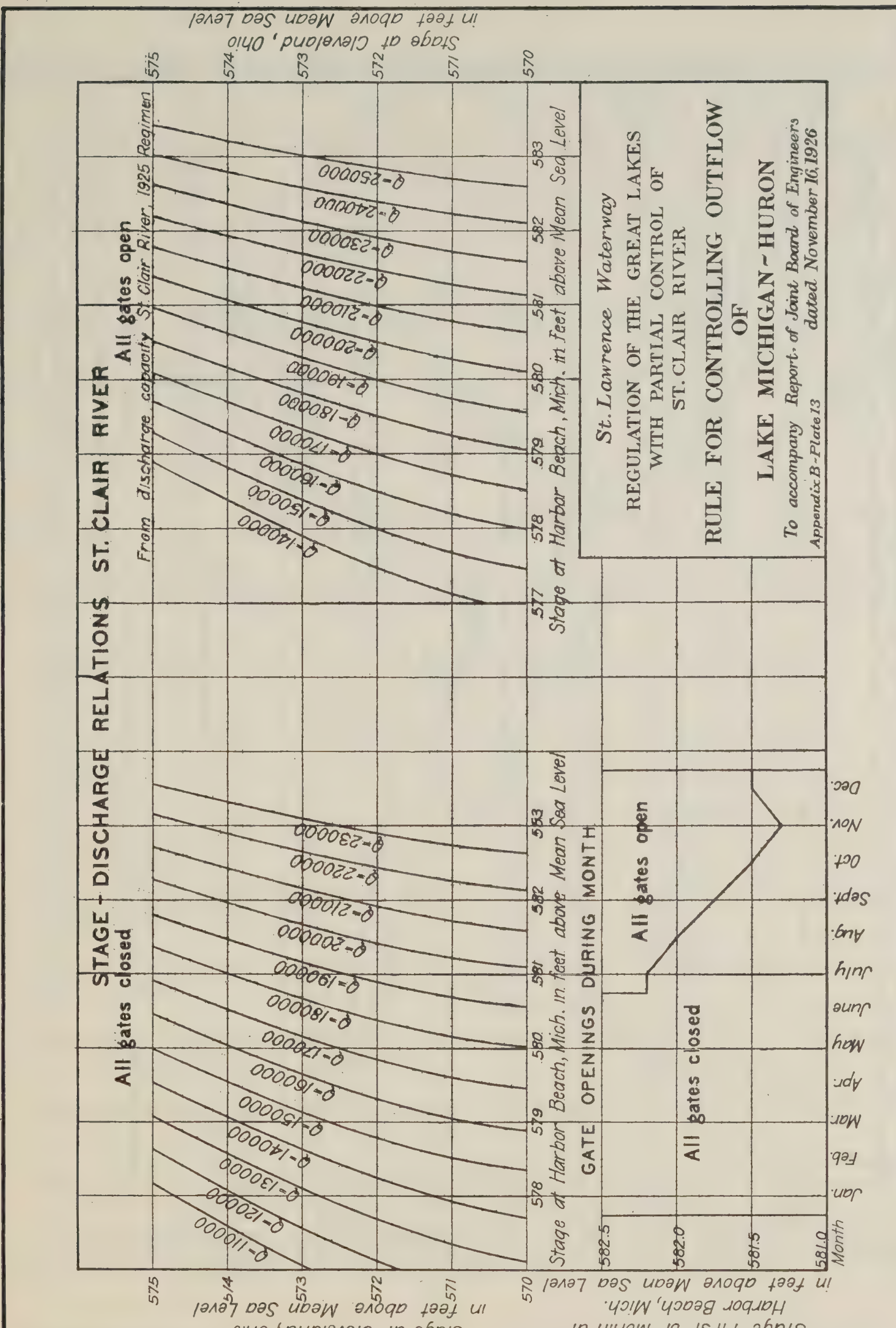
Appendix B-Plate 11

APPENDIX B - PLATE 12

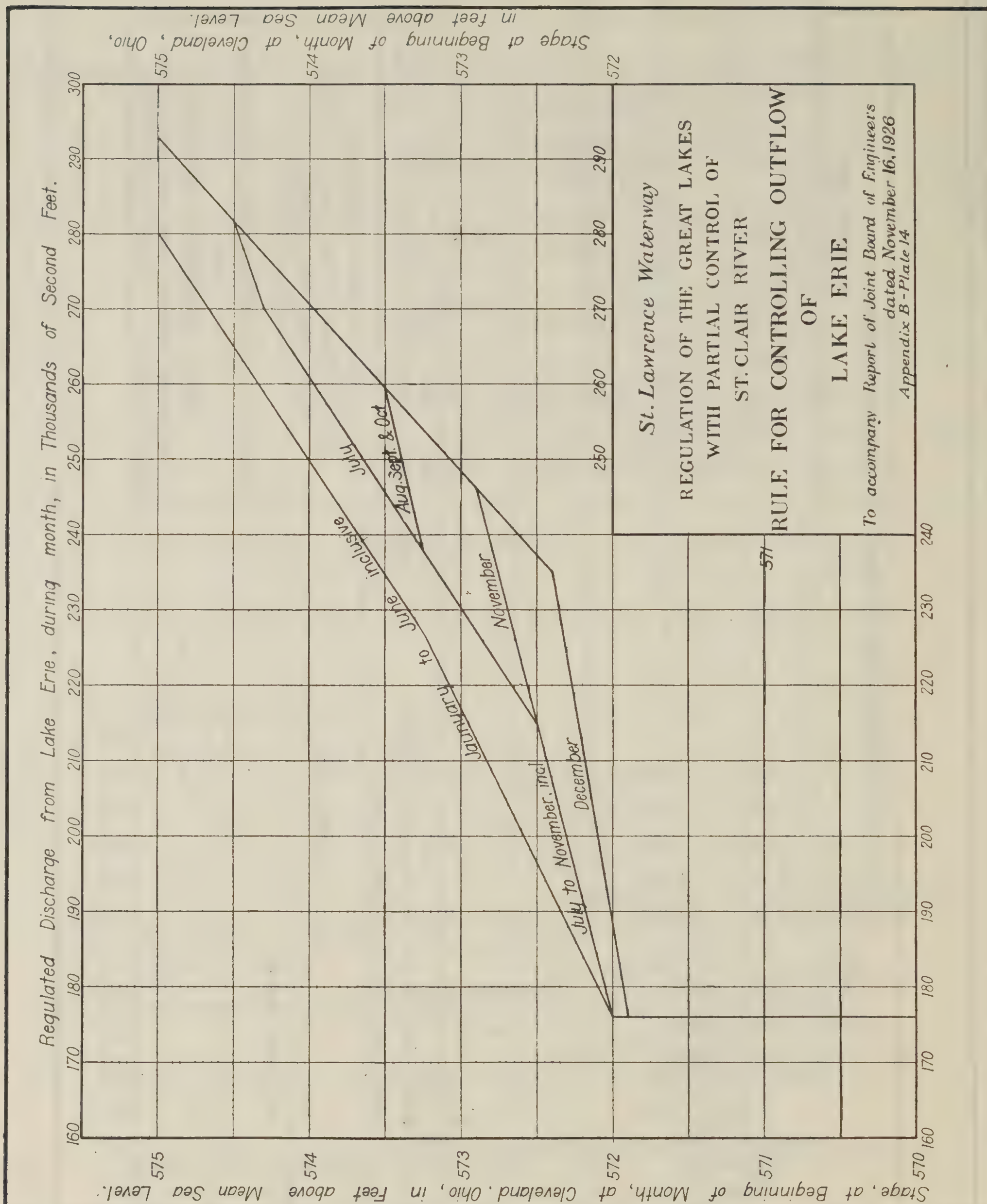


St. Lawrence Waterway
REGULATION OF THE GREAT LAKES WITH PARTIAL CONTROL OF ST. CLAIR RIVER
RULE FOR CONTROLLING OUTFLOW OF LAKE SUPERIOR
To accompany Report of Joint Board of Engineers dated November 16, 1926
Appendix B - Plate 12

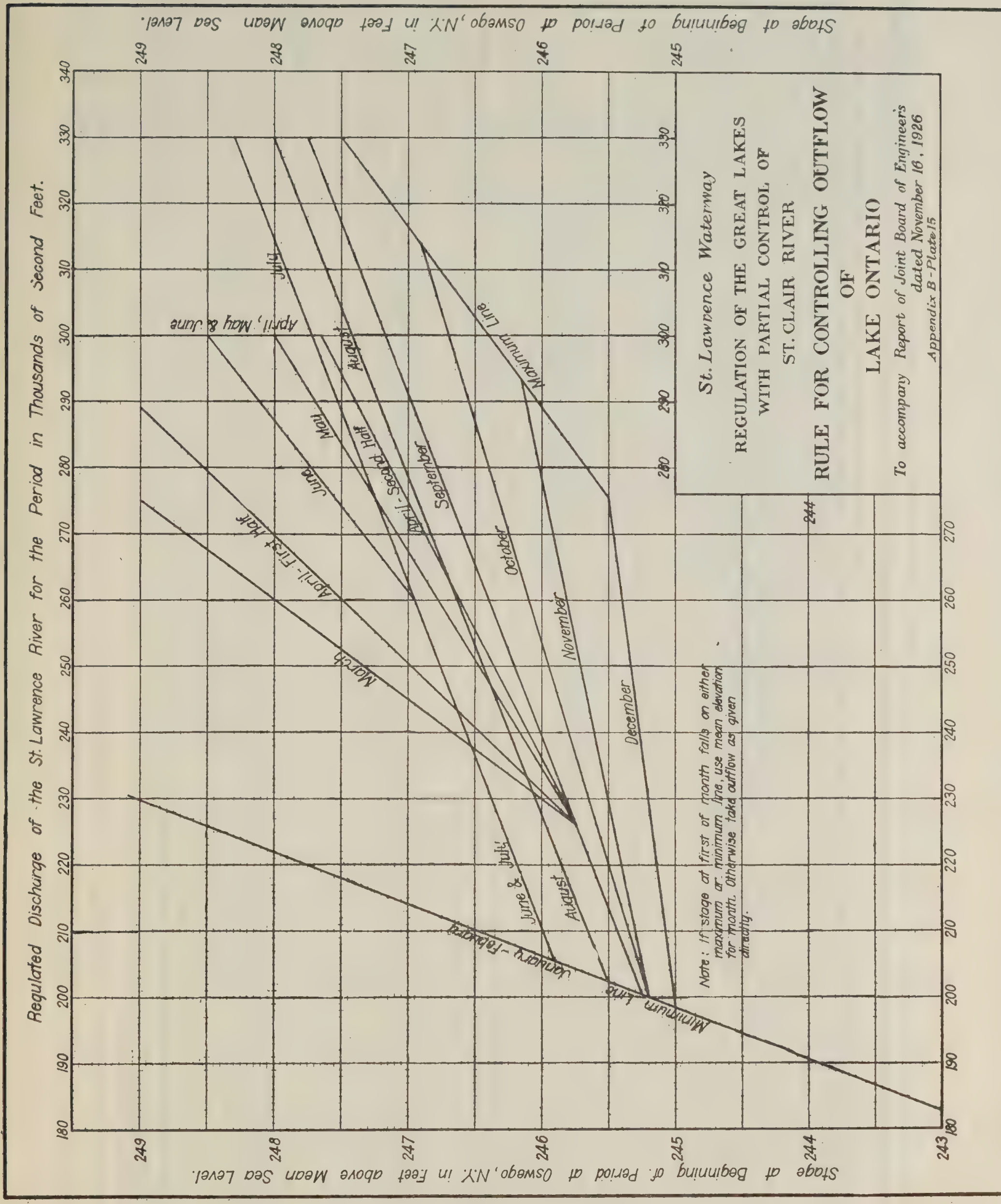
APPENDIX B - PLATE 13

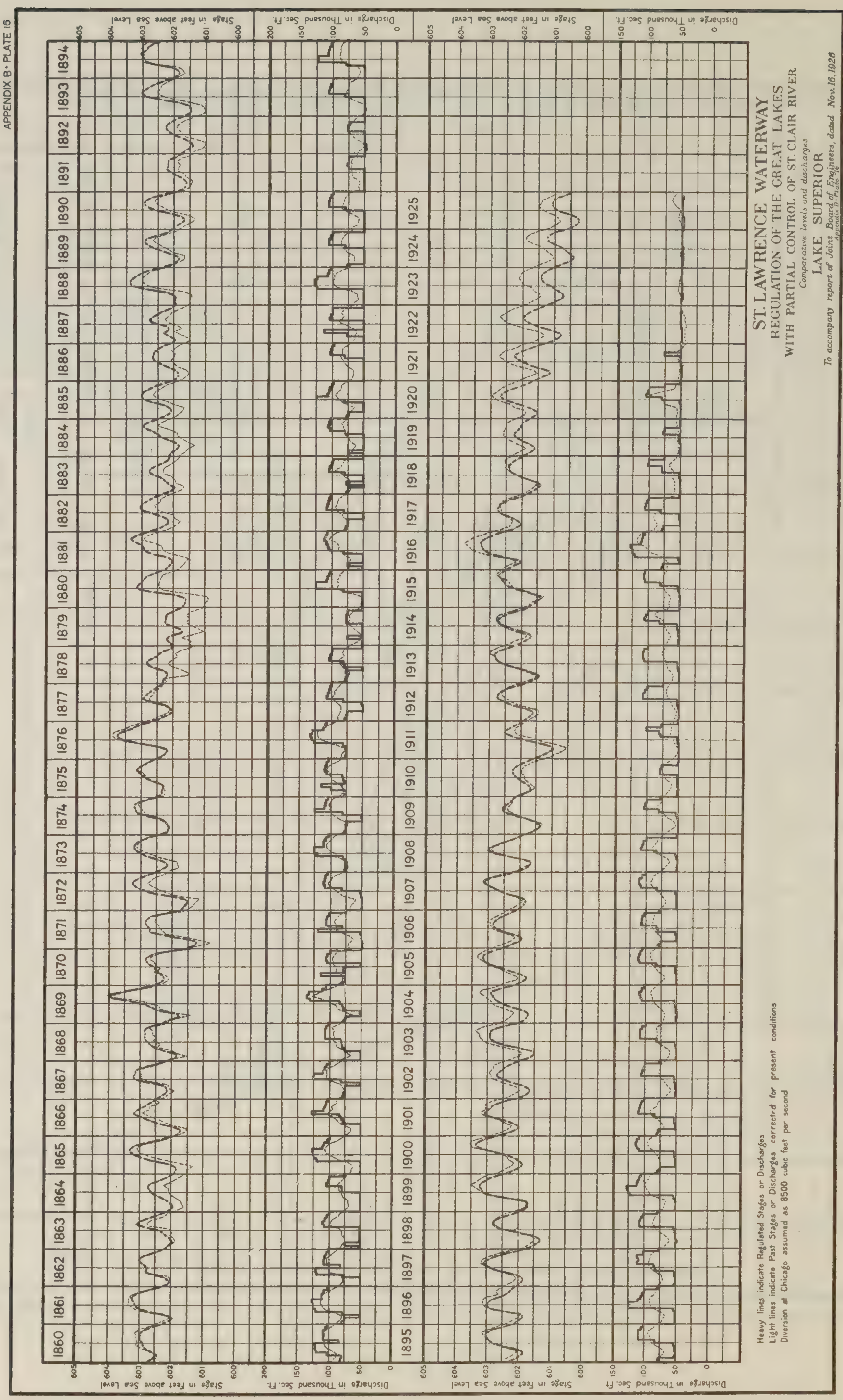


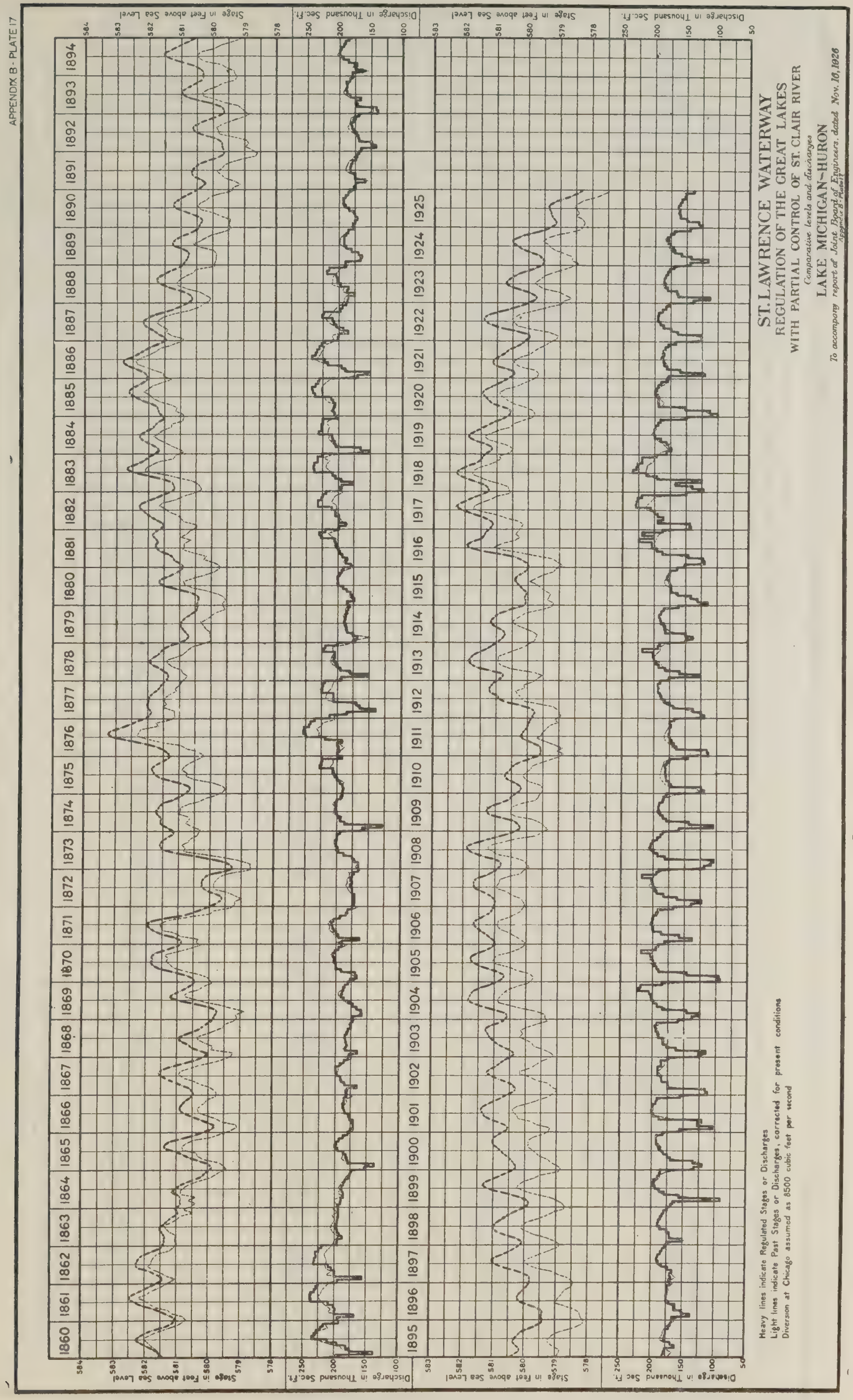
APPENDIX B-PLATE 14

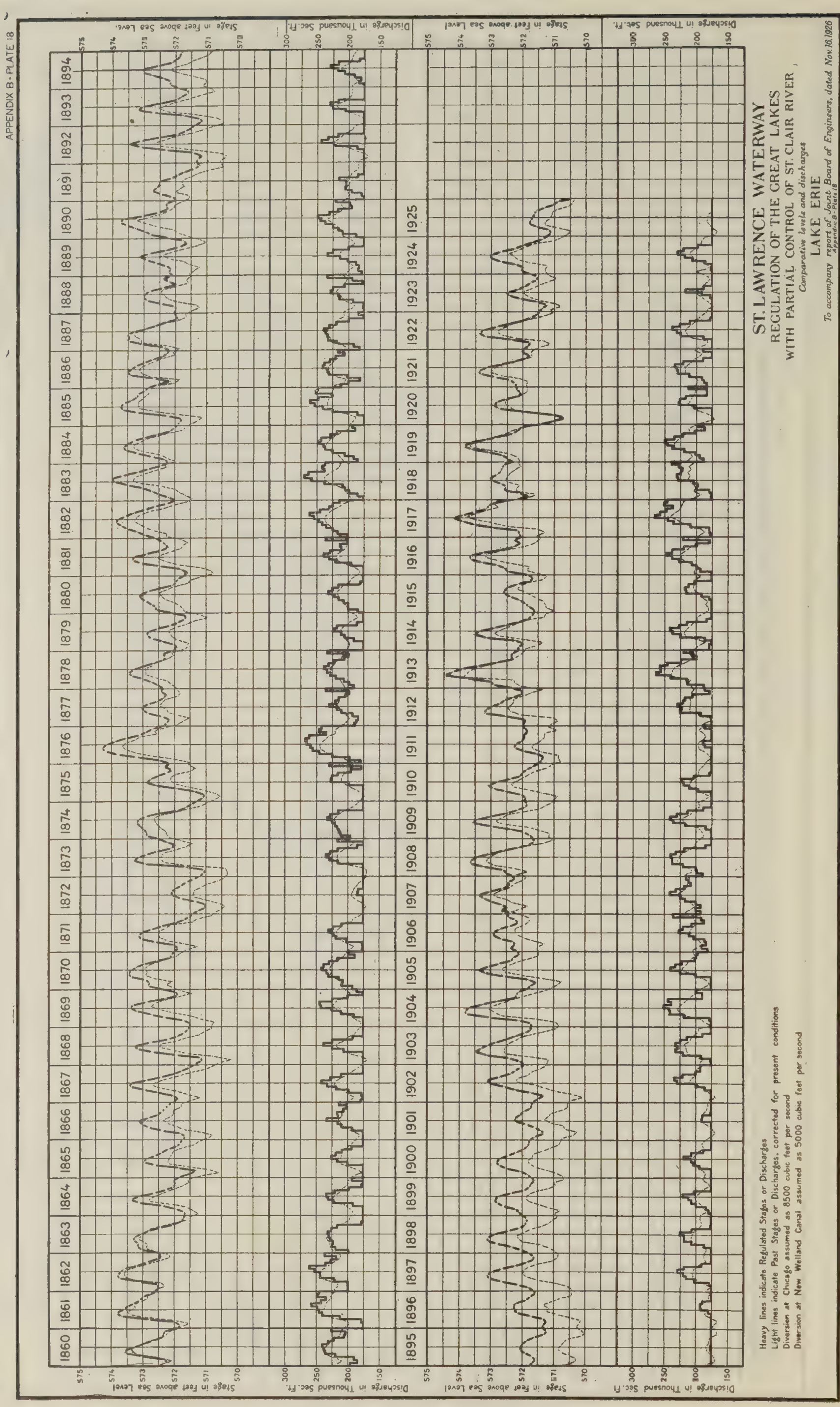


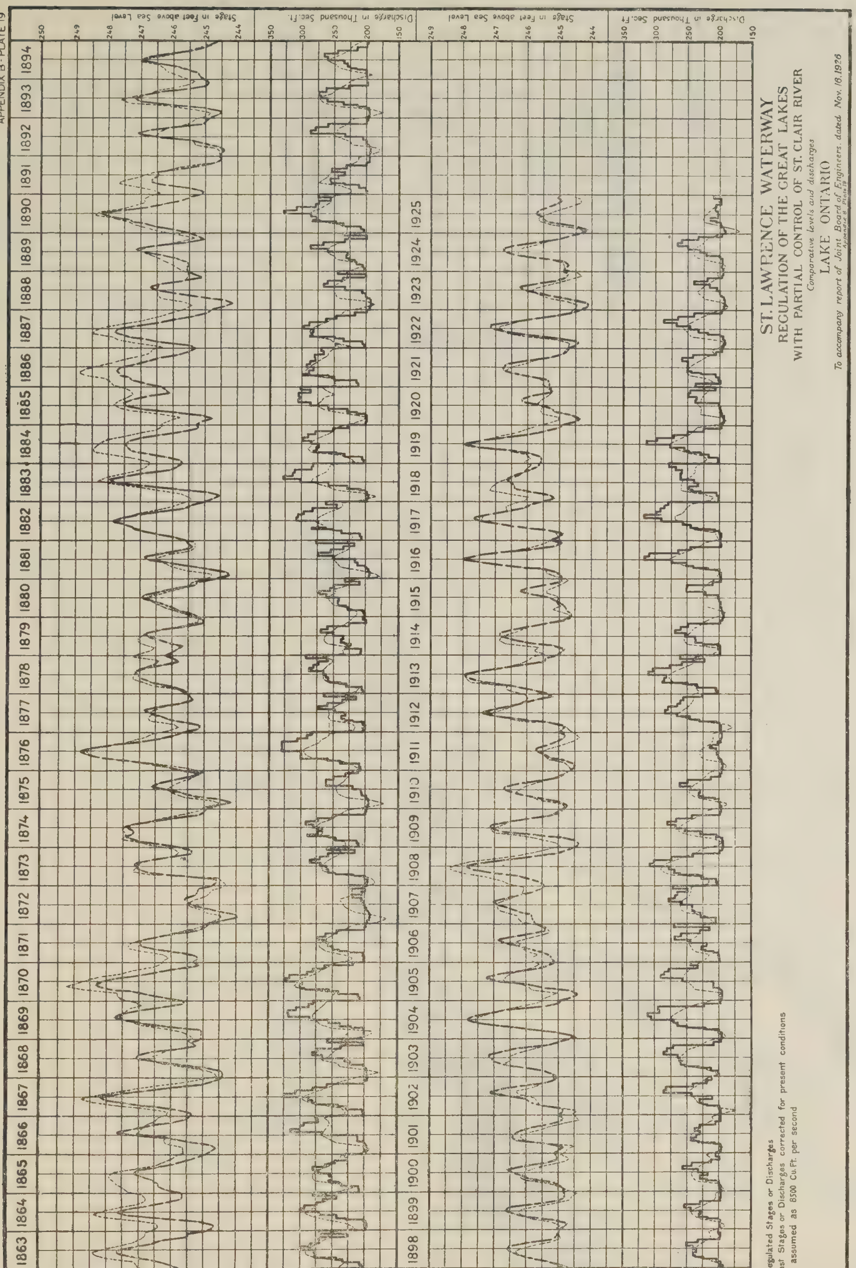
APPENDIX B - PLATE 15

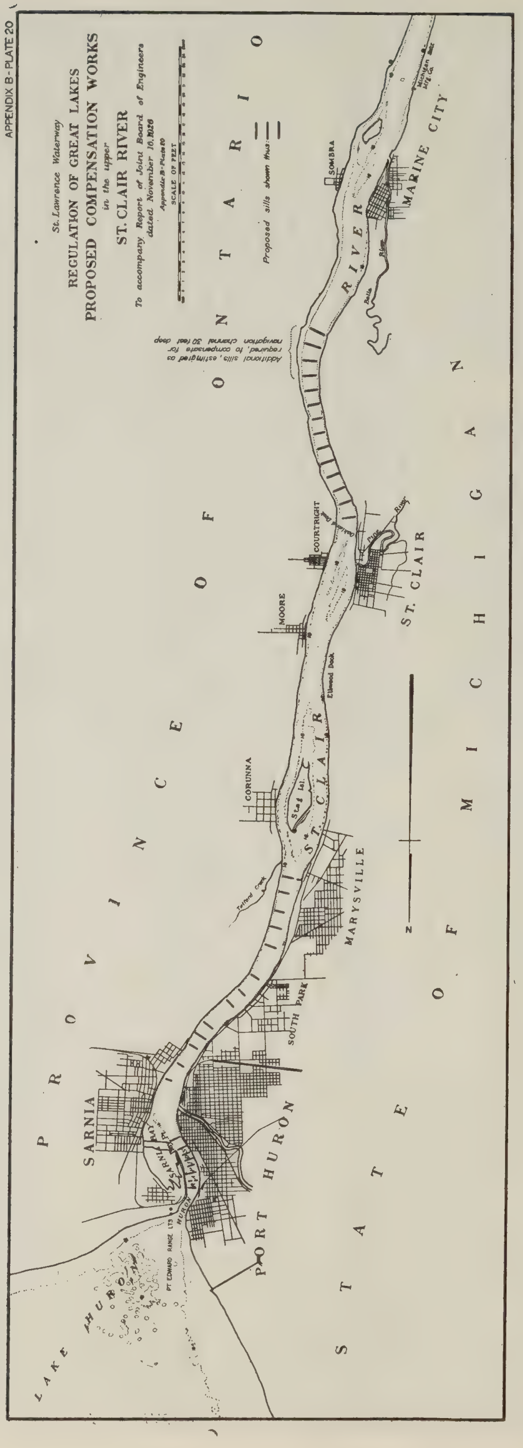



APPENDIX B • PLATE 16
Stage in Feet above Sea Level
Discharge in Thousand Sec. Ft.
ST. LAWRENCE WATERWAY
REGULATION OF THE GREAT LAKES
WITH PARTIAL CONTROL OF ST. CLAIR RIVER
Comparative levels and discharges
LAKE SUPERIOR
To accompany report of Joint Board of Engineers, dated Nov. 16, 1926
Appendix B Plate 16
Heavy lines indicate Regulated Stages or Discharges
Light lines indicate Past Stages or Discharges corrected for present conditions
Diversion at Chicago assumed as 8500 cubic feet per second

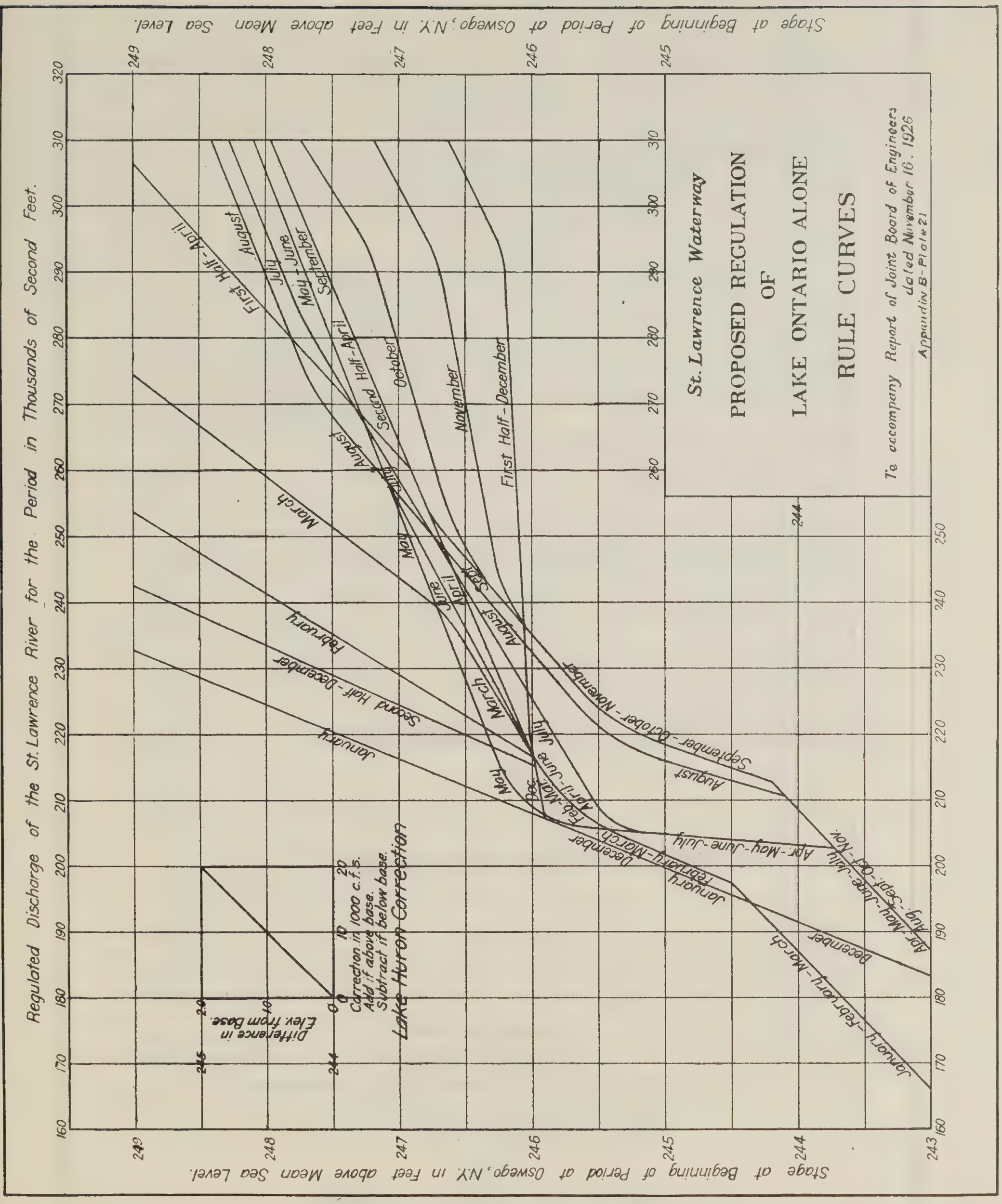

APPENDIX B - PLATE 17
ST. LAWRENCE WATERWAY
REGULATION OF THE GREAT LAKES
WITH PARTIAL CONTROL OF ST. CLAIR RIVER
Comparative levels and discharges
LAKE MICHIGAN-HURON
To accompany report of Joint Board of Engineers, dated Nov. 16, 1926
Heavy lines indicate Regulated Stages or Discharges
Light lines indicate Past Stages or Discharges, corrected for present conditions
Diversion at Chicago assumed as 8500 cubic feet per second
Stage in Feet above Sea Level
Discharge in Thousand Sec. Ft.


APPENDIX B - PLATE 18
ST. LAWRENCE WATERWAY
REGULATION OF THE GREAT LAKES
WITH PARTIAL CONTROL OF ST. CLAIR RIVER
Comparative levels and discharges
LAKE ERIE
To accompany report of Joint Board of Engineers, dated Nov. 16, 1926
Appendix B - Plate 18
Heavy lines indicate Regulated Stages or Discharges
Light lines indicate Past Stages or Discharges, corrected for present conditions
Diversion at Chicago assumed as 8500 cubic feet per second
Diversion at New Welland Canal assumed as 5000 cubic feet per second
Stage in Feet above Sea Level
Discharge in Thousand Sec. Ft.
1860 1861 1862 1863 1864 1865 1866 1867 1868 1869 1870 1871 1872 1873 1874 1875 1876 1877 1878 1879 1880 1881 1882 1883 1884 1885 1886 1887 1888 1889 1890 1891 1892 1893 1894
1895 1896 1897 1898 1899 1900 1901 1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913 1914 1915 1916 1917 1918 1919 1920 1921 1922 1923 1924 1925

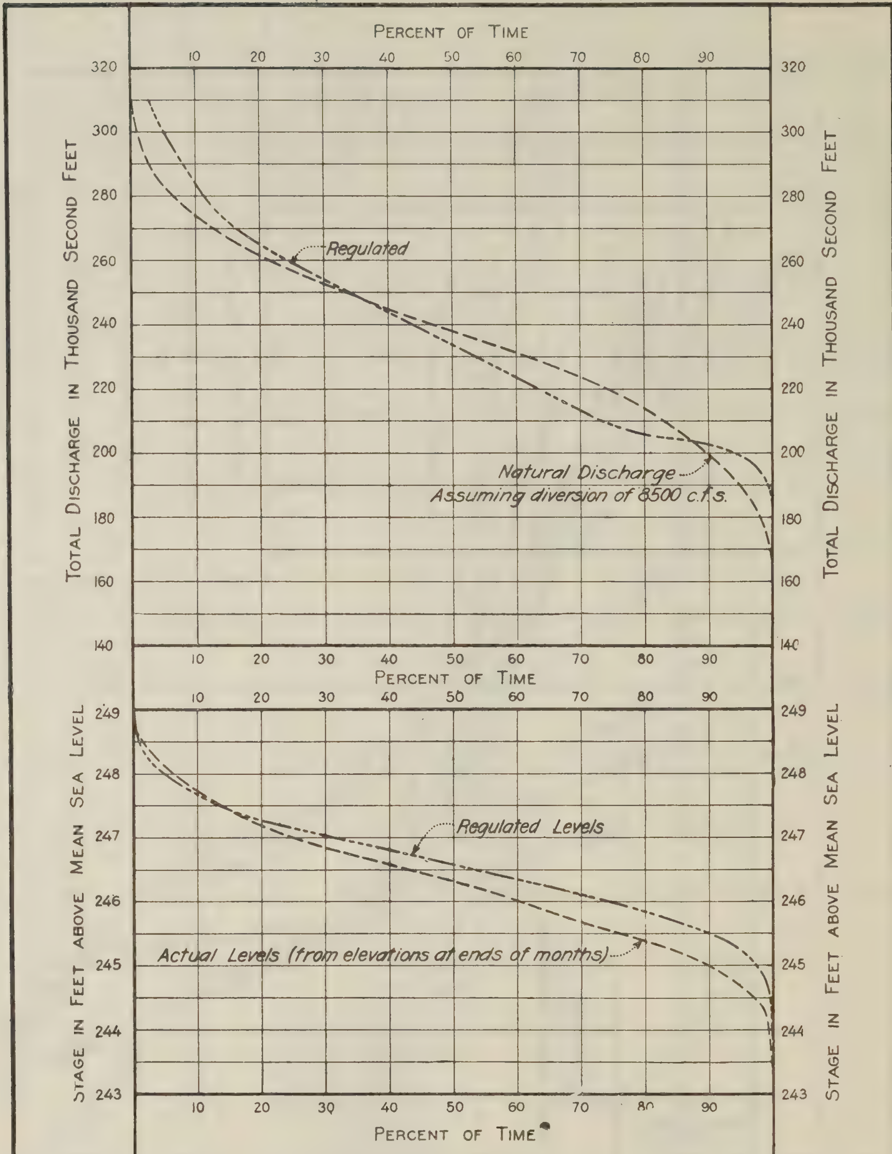

APPENDIX B - PLATE 19
ST. LAWRENCE WATERWAY
REGULATION OF THE GREAT LAKES
WITH PARTIAL CONTROL OF ST. CLAIR RIVER
Comparative levels and discharges
LAKE ONTARIO
Heavy lines indicate Regulated Stages or Discharges
Light lines indicate Past Stages or Discharges corrected for present conditions
Diversion at Chicago assumed as 8500 Cu.Ft. per second
Stage in Feet above Sea Level
Discharge in Thousand Sec.-Ft.


APPENDIX B-PLATE 20
St. Lawrence Waterway
REGULATION OF GREAT LAKES
PROPOSED COMPENSATION WORKS
in the upper
ST. CLAIR RIVER
To accompany Report of Joint Board of Engineers
dated November 16, 1926
Appendix B - Plate 20
SCALE OF FEET
Proposed sills shown thus:
Additional sills, estimated as required, to compensate for navigation channel 30 feet deep
PROVINCE OF ONTARIO
STATE OF MICHIGAN
LAKE HURON
PT. EDWARD RANGE LTS.
SARNIA
SARNIA BAY
PORT HURON
SOUTH PARK
MARYSVILLE
Talfourd Creek
CORUNNA
Stag Isl.
ST. CLAIR RIVER
Ellwood Dock
MOORE
COURTRIGHT
ST. CLAIR
Pine River
SOMBRA
Belle River
MARINE CITY

APPENDIX B - PLATE 21



APPENDIX B - PLATE 22



St. Lawrence Waterway

PROPOSED REGULATION OF LAKE ONTARIO

DURATION CURVES OF DISCHARGE FOR YEAR AND LAKE LEVELS DURING

NAVIGATION SEASON APRIL 15, TO DECEMBER 15.

PERIOD 1861 - 1925

To accompany Report of Joint Board of Engineers dated Nov. 16, 1926

Appendix B - Plate 22

APPENDIX C

DETAILED PLANS AND ESTIMATES FOR THE IMPROVEMENT OF THE ST. LAWRENCE

UNIT COSTS

1. The extended study made by the Board of the probable cost of the works has led to the adoption of unit costs in the several sections as follows:—

2. Thousand Islands Section. The material to be excavated is principally granite rock, and practically all excavation is subaqueous. The basic unit cost is taken as $10 per cubic yard for excavation with a cutting face of at least 4 feet, suitably increased to cover the proportional amount of excavation having a less cutting face, and further increased to cover the cost of transporting the plant to and from the work.

3. International Rapids Section. The material overlying rock in this section is generally a mixture of clay, sand, gravel, hardpan, and boulders. The swifter portions of the river, where most of the dredging is to be done, is generally paved with boulders.

4. Material for Concrete. Crushed rock can be obtained from quarries on the American shore between Gouverneur and Potsdam, with a rail haul of from 30 to 50 miles; from quarries north of Cornwall, with a short rail haul, or by water from the Thousand Islands region, with about 100 miles haul. It is doubtful whether the rock obtained from excavation will be suitable for concrete, since the borings show that it contains shale.

5. Sand can be obtained from extensive deposits north of Prescott. The river bed above Ogdensburg, and sand and gravel pits which may be developed in the vicinity of the work, offer possibilities of alternative sources.

6. Unit Prices. Considering the nature of the material to be excavated, and the sources of the material for concrete, the following basic unit prices are used:—

	Per Cubic Yard
Excavation, earth, dry	$ 65
Dredging, other than rock	90
Rock, dry ....$1.60 to	1 75
Dredging, rock	4 25
Embankments by United States Section	75
Embankments by Canadian Section ....90 and	60
Concrete, mass, in locks, etc.	10 00
Concrete, mass, in dams	12 00
Concrete, mass, in power house	15 00

The basic prices for excavation and fill are departed from when the special conditions, such as the disposal of excavated material, indicate that different prices should be adopted.

7. Lake St. Francis Section. On account of the nature of the material to be excavated in this section, and the disposal areas available, the unit price taken for soft mud overlying sand and gravel is 55 cents per cubic yard.

8. Soulanges and Lachine Sections. In the Soulanges Section the bulk of the material to be removed is marine clay. This material can be easily excavated by hydraulic dredges where conditions permit the use of such plant. The unit

prices adopted for the excavation of marine clay in this section varies from 35 to 55 cents per cubic yard, depending upon the conditions of disposal. The unit prices adopted for the removal of boulder clay is 65 cents per cubic yard. The unit price for excavation of rock, dry, is taken at $1.60 per cubic yard.

9. In the Lachine Section the overburden is largely boulder clay, and the price adopted for earth is 65 cents per cubic yard, that adopted for the excavation of shale rock is $1.20 per cubic yard, dry, and $3 per cubic yard, wet. Other rock is at $1.60 per cubic yard, and $4.25, wet.

10. The work proposed in the Soulanges and Lachine Sections involves the excavation of large amounts of solid rock. Much of this rock, when crushed and washed, will be suitable for concrete. Sand can be obtained from deposits near the mouth of the Chateauguay river and in the Lake of Two Mountains.

11. On account of the ease with which rock and sand can be obtained in these sections, the unit price for concrete is taken at $1 less per cubic yard than in the International Rapids Section.

12. Flowage. In compiling estimates of flowage damage, a detailed field examination was made of all properties affected. Liberal allowances were made in all cases, and due cognizance was taken of severance and other disabilities which owners might suffer by execution of the work proposed. No allowance has been made for water rights, but the values of leases of water-power on Government canals has been included in the estimates under the terms of surrender provided therein.

NAVIGATION STANDARDS

13. Channels. In general, navigation channels are not less than 200 feet bottom width when flanked by two embankments, not less than 300 feet when flanked by one embankment, and not less than 450 feet when both sides of the channel are submerged.

In cases where navigation is carried through restricted stretches of river, a sectional area of 65,000 square feet is provided at mean stage. This is equivalent to a sectional area of about 70,000 square feet at high stages, and a maximum velocity somewhat less than 5 feet per second in such channels. In general, maximum velocities and channels 450 feet wide are used only in short stretches of river where the view is unobstructed and where cross-currents are not encountered. The minimum radius of curvature adopted is 5,000 feet with at least one-quarter mile of tangent between reversals. The alignment is drawn so as to eliminate cross-currents wherever possible.

14. Bridges. Bridges are designed to afford a least horizontal clearance of 200 feet at right angles to the channel, except where located at locks, where they span the entire channel. All bridges crossing the channel are drawbridges. In general, the draws are of the vertical lift type. The estimates are based on a lift affording 120 feet clearance, corresponding to the bridges in the New Welland Ship canal, but the clearance can be increased at any time at relatively small cost.

15. Locks. As stated in paragraph 113 of the Main Report, the locks conform in dimensions with those of the new Welland Ship canal, and have chambers 859 feet in length between inner quoinposts and 766 feet between breast wall and fender. Their clear width is 80 feet and the depth on the sills 30 feet. The general design of a typical lock is shown on Plate 1, Appendix C.

Power-House Design

15. The design of power-houses, for the large flow and varying heads on the St. Lawrence, was gone into with care. The conditions in general on the river call for power units of larger dimensions than have yet been built, and the Board recognizes the uncertain trend of present practice with regard to draft-tube design.

17. The Board established certain dimensional ratios and stability coefficients conforming to current practice. From tentative designs, a curve of quantities was prepared and is shown on Plate 2. This method of procedure secures a correct comparison between projects and safe estimates generally.

18. The prices used for power-house equipment are derived from curves prepared from many direct quotations coupled with actual prices of equipment recently installed in power stations. (Plates 3-8.)

19. Dykes.—The standard design for dykes adopted by the Board is shown on Plate 9.

Administration and Contingencies

20. To cover the costs of administration, engineering, and contingencies, a percentage of about 12½ per cent has been added to all estimates, including the estimated costs of power-house machinery.

21. The foundation conditions at the various dams cannot be definitely known until the sites are unwatered. The estimates are based on founding the structures from 3 to 8 feet below the rock surface indicated by the borings, besides providing a heel trench of ample dimensions. To cover the contingency that, when a site is unwatered, suitable foundations will be found at a somewhat lower elevation than is indicated by the borings, a special allowance of 10 per cent of the quantity of the concrete as computed on the above basis, has been added in case of each dam.

Datum Planes

22. The datum plane used in all plans west of Summerstown on lake St. Francis is mean sea level New York Harbour, United States 1903 adjusted levels, and the datum plane used in all plans east of that point is that of the Georgian Bay adjusted levels. The zero of the Georgian Bay adjusted datum is 0.30 foot below the Georgian Bay instrumental datum used in many published water-level records, and is 0.30 foot above United States 1903 adjusted datum at Ogdensburg.

THOUSAND ISLANDS SECTION

(Mile 0 to Mile 67)

23. As explained in the Main Report, the St. Lawrence river between Tibbetts point, at the outlet of lake Ontario, and Chimney point, at the foot of the section, is wide and deep for the greater part of the 67 miles embraced in the section. At numerous places, however, granite reefs endanger navigation. For a length of about 7 miles through the Alexandria bay narrows and for a length of about 3½ miles through the Brockville narrows, the river flows through a rocky gorge with an average velocity of about three feet per second, over a solid rock floor 150 feet below the surface at many points.

24. In this reach there are on the average about 200 hours of fog in the navigation season. Navigation through these two narrow stretches of river will be hazardous for the larger ships if a fog should close in while making the passage, since they cannot anchor on account of poor holding ground. In accordance with standards adopted, the minimum width of channels shown in these stretches is 450 feet. To enlarge the channels to a width of 600 in the Alexandria bay and Brockville narrows would be exceedingly expensive on account of the amount of solid rock requiring removal. To provide separate up and down channels would be less costly.

25. If found to be necessary, a series of landing cribs can be built along the north side of the channel at some of the points where solid rock is excavated. If this were done ships could reverse their engines and moor to these cribs on the downstream voyage should visibility be unexpectedly interfered with. As there is some doubt as to the necessity of these provisions and as landing cribs can be added when required, they are not included in the plans attached to this report.

26. Plans of the portion of the section in which the work is located are shown on plates 10 to 16.

27. The detail estimates of the excavation are as follows:—

CHANNEL 25 FEET DEEP

Excavation, rock, 64,000 cu. yds. at $12.50	$ 800,000
Overdepth, 12,000 cu. yds. at $12.50	150,000
Administration, inspection, and contingencies 12½ per cent	119,000
Total	$1,069,000
Rounded total	1,100,000

CHANNEL 23 FEET DEEP

Excavation, rock, 41,000 cu. yds. at $13.25	543,000
Overdepth, 7,400 cu. yds. at $13.25	98,000
Administration, inspection, and contingencies 12½ per cent	80,000
Total	$ 721,000
Saving in cost under channel 25 feet deep	348,000

CHANNEL 27 FEET DEEP

Excavation, rock, 96,000 cu. yds. at $12.00	1,152,000
Overdepth, 17,500 cu. yds. at $12.00	210,000
Administration, inspection, and contingencies 12½ per cent	170,000
Total	$1,532,000
Excess cost over channel 25 feet deep	463,000

ENLARGEMENT OF CHANNEL FROM 25-FOOT DEPTH TO 30-FOOT DEPTH

Excavation, rock, 98,500 cu. yds. at $12.00	$1,182,000
Overdepth, 25,750 cu. yds. at $12.00	309,000
Administration, inspection, and contingencies 12½ per cent	190,000
Total	$1,681,000

INTERNATIONAL RAPIDS SECTION

(Mile 67 to Mile 115)

28. Detailed Description. At Chimney point (mile 67) the first marked contraction of the river occurs. A fall of 0.5 foot takes place in the passage through the chain of islands which here cross the river. Two and one-half miles downstream the river enters the Galop rapids, lying north and south of Galop island. There is a fall of about 8 feet through these rapids. From the foot of the Galop rapids (mile 73) to the head of Ogden island (mile 82),

strong currents are found, particularly at the contracted sections at Sparrowhawk point, point Iroquois, point Rockway, and point Three Points. The fall from the foot of the Galop rapids to the head of the rapide Plat, at Ogden island, is about 12 feet; and through the rapide Plat about 11 feet. From the foot of the rapide Plat, at Morrisburg (mile 85), to Weavers point (mile 92) the river is generally contracted, with strong currents and a fall of approximately 5 feet. It then flows through a fairly broad reach with small slope, to the head of Croil island (mile 95). There are strong currents, and a fall of about 4 feet, through the contracted channel north of Croil island, known as the Farran Point rapids. The river then flows four miles with moderate current and slight slope to the head of the Long Sault rapids (mile 102). The Long Sault rapids, with a fall of 30 feet, are the most formidable in the section. From the foot of these rapids to the town of Cornwall (mile 111) the currents are strong and the fall about 15 feet. The total fall through the section is 92 feet at mean river stages.

29. PRESENT NAVIGATION. Present upbound navigation passes around the rapids through a series of lateral canals; the Galop canal around the Galop rapids and the swift water above the town of Iroquois; the Morrisburg canal around the rapide Plat; the Farran Point canal around the Farran Point rapids; and the Cornwall canal around the Long Sault rapids and the swift water below them. Downbound commercial navigation runs some of the rapids, and some passenger boats run them all.

30. TOWN AND VILLAGES. The Canadian towns and villages on the river bank in this section, which will be affected by the improvement, are as follows:—

	Population
Cardinal, mile 73	1,241
Iroquois, mile 79	916
Morrisburg, mile 85	1,381
Altsville, mile 95	350
Farran Point, mile 97	296

31. Dwellings and farm buildings are located along the river bank throughout the section.

32. The town of Wales, population 250, lying on Hoople creek about a mile from the river bank, is below the maximum level to which the water surface could be raised.

33. The villages of Moulinette and Mille Roches (population 829) are located on Bergen lake, and will be affected if the level of that lake is raised.

34. On the United States side, the only town directly affected is Waddington (mile 83), most of which lies well above the maximum level to which the water can be raised. A small collection of houses known as Louisville Landing (mile 95) is located at so low an elevation as to be affected by any substantial rise in the river levels. In general, however, dwellings and farm buildings on the United States shore affected by the raising of the river levels are far less numerous than those on the Canadian shore.

35. PRESENT POWER DEVELOPMENTS. Water leases have been issued by the Department of Railways and Canals of the Dominion of Canada as follows:—

	Cfs.
From the Galop Canal—	
At Cardinal (Canada Starch Co.)	660
At Iroquois	329
From the Morrisburg Canal	1,630
From the Cornwall Canal—	
At foot of Bergen Lake (St. Lawrence Power Co.)	1,000
At Cornwall	1,331

36. On the United States side, a major diversion of water is made by the St. Lawrence River Power Co. through a power canal which leads from the river near the head of Long Sault island (above the Long Sault rapids) to the Grass river at Massena, where the power works are located. The water is discharged through the Grass river into the south channel of the St. Lawrence at Cornwall island. With the enlargement that has been made in the Grass River channel, the effective summer head at the power plant is a little more than 40 feet. The installed capacity at the power plant is reported as 86,000 horse-power.

37. Under an order of the International Joint Commission, dated December 6, 1922, the diversion at Massena is limited to 25,000 cfs. except when, in the opinion of a board of control constituted of two engineers, one appointed by each country, the diversion of a larger quantity will not injuriously affect navigation.

38. The average diversion through the Massena power canal at the present time is about 23,000 cfs. during the summer months and 16,000 cfs. during the winter months, the flow being reduced during the latter period to secure and maintain an ice cover over the power canal, in the interest of operating conditions.

39. Plans for Improvement. As explained in Appendix E on ice formation, paragraphs 10 and 11, several special features must be met in the improvement of the St. Lawrence river. The river valley is shallow and restricted for many miles below Galop rapids, and water levels above the Galop Control are subjected to uncontrollable oscillation due to changes in barometric pressure and wind. A typical fluctuation of levels which barometric changes set up on the St. Lawrence is shown on plate 25. Property values along the shores of lake Ontario prevent water levels being raised high enough to secure useful ice covers between Chimney point and Morrisburg without extensive enlargements of the channels.

40. East of Cardinal, the general elevation of the land near the river is below the level of lake Ontario. Nearly all the towns and villages in the district are located on this low strip of territory and any substantial raise in the water levels will require readjustments at these towns.

41. In this section solid rock outcrops at several points, but is at a suitable elevation for foundations of dams and power houses at only a few places.

42. For the improvement of the International Rapids section of the St. Lawrence, the Board has closely considered the following general forms of improvement:—

(1) Full single-stage schemes with the Long Sault reach at maximum level and a free navigation channel at Galop rapids.
(2) Two stage schemes with an upper dam and power houses at either Ogden island or Crysler island, and with a lower dam and power houses at Barnhart island.
(3) Partial single-stage schemes with lock and control dam at Galop rapids and the Long Sault reach held at nearly maximum level with a long free spillway.

43. In each of these foregoing forms of improvement, navigation is provided by means of side canals and locks past the dams.

44. Full Single-stage Plan. As shown in paragraph 144 of the Main Report, the design of full single-stage projects can be varied in several ways. The dam at the foot of the section can be built in different locations, navigation

channels at Galop rapids can follow a number of routes, and channel enlargement between Lotus island and Morrisburg can be made by widening present channels or excavating new ones.

45. A full-stage project with navigation channels north of Galop island and a dam at the foot of Barnhart island has been drawn up by the United States section. It will be referred to as Project No. 1-242. This plan is typical of what can be done with a single-stage development as regards cost and power capacity, but can be modified in a number of particulars. It is shown on plates 17 to 24. The estimated cost is $235,000,000. Detail estimates will be found in table 1.

46. The chief works in this project are as follows:—

(*a*) A free open channel for navigation north of Galop island with control gates in the channels north of Adams island and south of Galop island.

(*b*) Such channel enlargement between Lotus island, at the foot of Galop rapids, and Morrisburg as is necessary to give 95,000 square feet sectional area at ordinary operating levels.

(*c*) A dam with United States and Canadian power houses at the foot of Barnhart island. These directly control the level of lake Ontario.

(*d*) A side canal with two locks for carrying navigation past the dam and power houses.

(*e*) Such embankments and drainage works as are required to protect the villages of Iroquois, Morrisburg, Aultsville, Farran point, Dickinson landing, and Wales from the raised levels of the river.

47. At Galop rapids all the river enlargement deemed to be necessary is made in one central channel. The approach channel has a bottom elevation of 215. It is carried through the upper end of Galop island, with a width of 800 feet and bottom elevation 210, and downstream with a width of 600 feet and same depth along the north Galop channel to below Lotus island. The channel at the foot of the rapids south of Lotus island is also enlarged.

48. In the present north and south Galop channels, piers with Stoney sluice gates are placed. These gates are 50 feet in width and the sills conform generally to the natural rock surface which crosses the river at this point. Similar gates extend across a portion of the approach to the central channel, leaving a clear opening of 500 feet with sill at elevation 215.

49. Under the proposed program for the regulation of lake Ontario, it is necessary, in about one year out of six, to discharge water at an excess rate during the first part of December, with lake Ontario at relatively low level, in order that the subsequent outflow during the winter may be restricted without incurring the danger of excessively high levels in the spring. The maximum requirement at such times is a discharge of 310,000 cfs. with lake Ontario at elevation 246.5. Under such conditions the fall at the Galop from Butternut island to the foot of Lotus island is computed by the United States section to be 3.25 feet, and the maximum velocity in the navigation channel, at the pass through the contraction works, at about 6 feet per second.

50. At Sparrowhawk point, Toussaint island, Rockway point, and other places between Lotus island and Morrisburg, river enlargements are shown. These are designed to give 95,000 square feet at river elevations corresponding to water level of 246.5 in lake Ontario and 210,000 cfs. flowing in the river. By the regulation of lake Ontario as submitted in Appendix B, the January discharge will give an average velocity of 2.25 feet per second in this reach.

51. Dykes are shown in front of the villages of Iroquois, Aultsville, Farran point, and Wales, and also in front of the town of Morrisburg. On both shores of the river from Weavers point to the power houses and dam at the foot of

Barnhart island, the line of dykes shown is almost continuous. The crest of the dykes is placed at 254.5 east of Weavers point and somewhat higher west of it. The tops of the dykes are $5\frac{1}{2}$ to 7 feet above the maximum level of lake Ontario.

52. The main dam and the United States and Canadian power houses in this project are at the foot of Barnhart island, just below a very deep narrow gorge in the river at this point. They are in a straight line and founded on rock which varies from elevation 104.0 to 113.0.

53. The elevation of the water surface at this point in summer is 159.7 at mean stage. In winter it rises quite frequently to elevation 180 and levels as high as 190.0 have been recorded on a number of occasions. The sectional area of the river at the site of the dam is about 38,000 square feet at mean stage, but about one mile above it is much less and the high velocities generated by this restriction carry through the part of the river where the dam is shown.

54. The open cofferdam method is intended to be used for all the work at this point, but should it be decided to use the pneumatic process for the dam section, the estimate will not be materially increased.

55. The dam is found on rock which has been found to be about 51 feet below water level at this point. It is 2,975 feet in length. It is provided with 46 Stoney sluice gates, 50 feet in width by 25.5 feet in height, with sills at elevation 223. The piers between the gates are 15 feet in thickness. The discharge capacity of the sluices is sufficient to pass the maximum flow occurring at minimum pool level. The depth of the foundations permits of a design in which the energy of the falling water will be dissipated in the pool at the toe of the dam, without danger to the structure.

56. Power Houses. Two power houses are shown at this dam; they are at either end and in line with the dam. Each is 1,750 feet in length, and is capable of housing 22 main units and 3 auxiliary units. The main units are designed to deliver approximately 54,000 horse-power each at full summer head of 85 feet. At the predicted winter head of 75 feet, their capacity will be about 45,000 horse-power each. Sluices to carry off ice and trash are to be provided at the shore ends of the power houses. Both power houses are located outside of the main river channel. The solid rock surface on which the United States power house is to be built is about 55 feet below the water level of the river in summer and 75 feet below the water level in winter. The Canadian power house will be on rock from 10 to 50 feet higher.

57. A spur from the New York Central Railroad (Ottawa Branch) as diverted will run to the United States power house. A spur from the Canadian National Railway will run to the Canadian power house.

58. An alternative site for a dam and power houses at this locality is presented in the plans submitted in 1926 by the Frontier Power Corporation to the state of New York, and is indicated on plate 22. This site is at Hawkins point, about one-half mile upstream from the site above described. The foundation rock under the shore here lies from 5 to 15 feet lower than at the site downstream, but requires further exploration. The unwatering program proposed at the Hawkins point site is to divert the river through a channel excavated through Hawkins point. The dam as finally constructed will extend across both the diversion channel and the natural channel. Parallel estimates with a dam and power house at this site are given in table 2.

59. As pointed out in the Main Report (par. 144), the dam can be located at the head of Barnhart island and the power houses at the foot of that island if the foundation conditions at either site above described are regarded as unduly difficult. The estimates of cost with this arrangement are given in table 3.

60. The side canal used for carrying navigation past the dam at the foot of Barnhart island crosses over a tongue of land between Robinson bay and the mouth of the Grass river. It has two lift locks, but no guard lock. The lift of the upper or Robinson bay lock is about 42 feet and that of the lower or Grass river lock about 46 feet. The foundation of both these locks is carried to solid rock, which is at elevation 122 at the upper lock and 105 at the lower lock. The upper lock of this side canal is to be equipped with duplicate gates, fender chains, and an emergency wicket dam. An upper entrance pier 1,200 feet long is provided on one side and an entrance embankment 1,500 feet long on the other side.

61. To afford a straight river approach to the lock at Robinson bay a channel 450 feet wide is excavated across the point of land above the entrance. The Robinson Bay lock has its upper gate sills at elevation 207, lower gate sills at elevation 169, main coping at elevation 251.5, and lower coping at elevation 204.

62. The Grass River lock has its upper gate sills at elevation 169, lower gate sills at elevation 122, main coping at elevation 204, and lower coping at elevation 160. The upper and lower gates are in duplicate, and an unwatering gate is provided at each end of the lock outside of the service gates. No emergency dam is provided for this lock, since in the event of the failure of the lock gates the pool would be nearly drained by the time that the dam could be closed.

63. Water to maintain the level of the pool between the locks is to be supplied through an auxiliary culvert in the walls of the upper lock. To prevent rise in the pool, a waste weir is provided adjacent to the lock. Normal regulation of the pool is provided by 8 sluices, with sills at elevation 194, closed by crest gates 15 feet in width. Under these lie 8 submerged sluices, closed by gates 15 feet by 11.5 feet. These are to be operated only if ever necessary to discharge the great volume of water, estimatd at around 60,000 cfs., which would result from a failure of the gates of the upper lock. The fall from the intermediate pool to the mouth of the Grass river is divided into two drops at the waste weir, the crest of the lower drop being at elevation 154. The waste weir is designed with pile foundations with a concrete cut-off wall extending to rock under the upper and lower weirs.

64. To prevent currents caused by a flood in the Grass river from interfering with the approach to the lower lock, the mouth of the river is to be straightened by a compensating channel, and separated from the lock approach by a rock dyke.

65. The Ottawa branch of the New York Central railroad is to be diverted from its present crossing of the south Cornwall channel to a crossing immediately below the lower gates of the Grass River lock, where it will cross the canal by a bascule span. It will rejoin the present line by a cantilever span over Pollys Gut.

66. Highway connection with the United States power house, and to the land north of the canal, is to be afforded by a ferry across the intermediate pool, in order to avoid an additional bridge over the canal.

67. The winter operation of power plants with the completed plan is based on the creation of an ice cover extending from Lotus island to the power houses at Barnhart island, but with an open channel, 3½ miles in length from Butternut island to the foot of Lotus island. The area of open water to be expected is about 1.8 square miles. If the accumulation of floating ice to be dealt with is limited to that produced in this open reach, no material gorging can occur. Temperature measurements show that the mean temperature of the water, as

it leaves the present ice sheet above Ogdensburg and Prescott, is slightly above the freezing point, and the amount of ice manufactured in this open reach will be reduced in consequence, since the water must be chilled to the freezing point before the manufacture of ice can begin.

68. To insure the conditions above outlined, the continuity of the ice sheet above Butternut island should be maintained, in order that an ice jam may not form at the foot of the relatively fast water through the Galop channels. At the present time the ice sheet between Ogdensburg and Prescott is broken up by the powerful car ferry which operates between the two towns, in order to assure the lane required for the ferry operation. At the present time, the ice so broken out is carried by the current through the entire section, adding to the great accumulation of ice which forms at the foot of the section. After the river has been improved, and an ice sheet has formed to the foot of the Lotus island, the breaking up of this ice may become a more serious matter. Proper control should therefore be exercised over the ferries to prevent them from making ice conditions worse than they would be if nature were allowed to take its course.

69. Between Chimney point and Butternut island, the ice situation is now variable. During some years an ice sheet forms across the river, in others an open channel leads through the section, either through the north channel or through the main channel on the south of Drummond island. After the improvement of this part of the river has been completed, conditions should be more favourable for the formation of an ice sheet because of the enlargement to be made at Chimney point.

70. It is proposed to deposit some of the waste rock from the excavation of the Chimney Point Channel to form artificial islands in shoal water at the sides of the natural channel opposite Drummond island, in order to assist in holding the ice sheet. Booms may also be employed to form an ice cover in this reach at the start of winter.

71. In executing the works shown in project No. 1-242 at Galop rapids, no large amount of unwatering of river channels is required other than that associated with the dams and control structures.

72. In this plan three wide sweeping curves carry navigation from Chimney point to Galop island. These can be reduced in length, but at large cost, by a cut through the sill which extends between Chimney island and Drummond island.

73. For the improvement of the river between Galop rapids and Morrisburg the full single-stage plan shows a sectional area of 95,000 square feet at elevation 242 at Morrisburg and 243 at Lotus island. Initially, it is intended to make this enlargement only sufficient to give 70,000 square feet at mean stage, and bring about subsequently the full enlargement to 95,000 square feet or such other section as experience indicates to be required. (See para. 138, Main Report.)

74. On the United States shore, the land submerged by the ponding of the river is largely waste land, and the dyking is limited to that necessary to contain the pool. From the United States power house a dyke extends to the hill at Robinson bay. This dyke ranges from 20 to 30 feet in height. The gaps in the line of hills extending from Robinson bay to Massena canal are closed by dykes. Suitable drainage ditches are provided to replace the natural drainage line cut by this line of dykes.

75. A concrete intake, with gates, is to be constructed to by-pass the entrance to the Massena Power canal, and after its completion the present

entrance is to be closed by a dyke. By this means, the existing power plant at Massena can be kept in operation until its load is taken over by the main power house at the foot of Barnhart island.

76. A dyke 20 to 30 feet in height extends from the Massena canal to the hills paralleling the river about two miles to the west. A few small dykes are required at the low points in this line of hills. An embankment is required at the head of Coles creek.

77. On the Canadian side of the river the value of the land justifies a more extended system of dykes. The line of dykes extends from the Canadian power house to the high land on Barnhart island, thence across the head of the channel between Barnhart island and Sheek island, across the head of the latter island and the head of Bergen lake to the Canadian shore. It extends along the line of the low hills which lie close to the river bank from the head of Bergen lake to Farran point. At Farran point, and at Aultsville, the dyke line is along the river front to afford these towns protection, its crest being about 17 feet above their main streets. The dyke line terminates on the high ground back of the river two miles west of Aultsville. The dykes along this line are of moderate height, generally less than 20 feet, and for much of the distance, their bases are above ordinary pool level.

78. To care for the drainage into the river cut off by these dykes, including the flow of Hoople creek, a ditch is to be constructed along the low ground back of the river, emptying into the head of Bergen lake. Concrete drops are required in this ditch at the entrance into the valley of Hoople creek, and at the outlet into Bergen lake. Concrete bridges are provided at all road crossings. Suitable dykes are to be constructed to prevent flood flows in this ditch from backing up into the low lying portions of Aultsville and Farran point, and pumping plants are to be provided to take care of the local drainage of these towns at such times.

79. The bottom width of the drainage ditch increases gradually from 6 feet at its head to 45 feet at its outlet into Hoople creek, and is 80 feet from Hoople creek to Bergen lake. The grade of the bottom of the ditch is at elevation 226.5 at the head, 219 at the head of the drop into Hoople creek, and 200 at the head of the section between Hoople creek and the drop to Bergen lake. The slopes range from about 0.85 to 0.6 foot to the mile, insuring velocities which will not scour.

80. The low lying portion of the town of Morrisburg is to be protected by a dyke along the water front, its crest being 14 feet above the lowest portion of the main street. Sewage from the town is to be collected in an intercepting sewer and pumped into the river. Drainage ditches and a pumping plant are to be provided to care for storm water drainage. Similar provision is made for the protection of the low lying portion of Iroquois.

81. As an alternative to the plan for dyking and draining the low lying portions of these towns, it may be found more desirable to expend the funds assigned to that purpose in moving the buildings to the high land in the immediate vicinity, under a town planning scheme worked out in co-operation with the citizens. The low lying portions of the towns, above the minimum pool levels, could then be filled to form public parks.

82. Massena Canal Intake. This intake is to be constructed with eleven sluices, each 16 feet in width, separated by piers 10 feet in thickness. When the pond is raised, the sluices are to be closed successively, and the weir built to crest elevation 220, the discharge during construction and after completion being controlled by gates 16 feet in width and 30 feet in height.

83. Lock at Head of Bergen Lake. To permit of the completion of the dyke line without interrupting present canal navigation, and to prevent the interruption of such navigation while the pool is being raised, a lock is to be constructed at the head of Bergen lake before the dyke crossing the present navigation route is constructed. This lock is to be 255 feet in length between quoin posts and 45 feet in width in the clear. The upper and lower gate sills are at elevation 184, permitting 14-foot navigation to pass through the lock at the present elevation of Bergen lake. The coping is at elevation 251.5. The gates at the head and foot of the lock are in duplicate. A culvert through the lock walls will provide the water supply to continue the present canal and water leases as long as may be desired.

84. Reconstruction of Railroads. It is necessary to raise the grade of the Canadian National Railway for a distance of 4¼ miles between Morrisburg and Aultsville, and for about one mile east of Iroquois. At the former location a realignment, shown on the drawings, will reduce the height of the embankment and permit the construction of the line while traffic is being carried on the present one. At the latter location, it will be desirable, for the sake of alignment, to raise the grade under traffic.

85. The terminus of the St. Lawrence Railroad, at Norwood, near Waddington, will be submerged by the proposed pool levels. It is planned, therefore, to provide a new terminus, just above the village, where the requisite navigation depth to the terminus will be afforded by the increased levels.

86. Road Relocation. On the United States shore it will be necessary to raise the present river road at a few points only between the head of the Galop and Waddington. The highway from Waddington to Massena will be reconstructed on a new straight alignment for 5.5 miles east of Waddington, and the river road thence to the head of the Massena canal will be reconstructed in places. Some road construction will be required to replace roads cut by the navigation canal.

87. On the Canadian side the highway along the river will require raising at a few low points above Iroquois. From a point about a mile above Iroquois to the head of Bergen lake, an extensive relocation of the shore highway is required. The estimates provide a concrete road. The easterly part of the relocation is on the dykes to be constructed here, the top width of the dykes, 40 feet, being ample for that purpose.

88. Two-Stage Plans. The design of two-stage projects can be varied in several ways. The upper dam and lock can be located at Ogden island near the head of the section where it will virtually act as a valve to control the flow out of lake Ontario even when the surface level above Galop rises and falls, due to changes of barometric pressure at the ends of lake Ontario. The upper dam and lock can also be located at Crysler island, farther downstream, where a higher head would be developed, but where the works would not control flows as effectively as in the upper location.

89. The two-stage project with upper dam and lock at Ogden island is mentioned in paragraph 131 of the Main Report. It will be referred to as Project No. 4-224. It is shown on plates 26 to 33. Detail estimates will be found on table 4. The chief works in this project are as follows:—

(1) A free, open channel south of Galop island for navigation, along with a diversion through Galop island and enlargement of channels north of that island.

(2) Channel enlargement between Lotus island and Ogden island to give 95,000 sq. ft. at ordinary operating levels.

(3) A dam, lock and power house at Ogden island, where a head varying from 17 ft. in summer to 12 ft. in winter is developed.
(4) Channel enlargement to 95,000 sq. ft. at a few places between Ogden island and Weavers point.
(5) A dam at the head of Barnhart island with power houses at the foot of that island, where a head varying from 67 feet in summer to 62 feet in winter is developed.
(6) A side canal with two lift locks and a pair of guard gates for carrying navigation past the dam. This canal is to be on the United States side of the river.
(7) Such embankments and drainage works as are required to protect the villages of Iroquois and Wales and the sewerage system of the town of Morrisburg.

90. In project No. 4-224, the power plants at Ogden island are designed to operate at about 100 per cent load factor, at least during the winter season. The power plants at the foot of Barnhart island are designed to take advantage of permissible fluctuations in the reach between Ogden island and Barnhart island. Transmission lines of the plants at Ogden island and Barnhart island must be interconnected and variation of load should be carried by the lower plant.

91. In this project the channel enlargement proposed between Lotus island and Ogden island gives the same sectional area as that shown in the full single-stage project No. 1-242, but the works at Galop rapids are somewhat different. The free channel provided for navigation at Galop rapids is located on the south side of Galop island and occupies the whole length of the present south channel.

92. The enlargement provided in this navigation channel does not give all the section required to secure low velocity and flat slope at this point. Further enlargement is required and is provided by a special diversion channel through the head of Galop island. The diversion channel is provided with piers and roller gates which can be closed to control emergency flows. This control structure is not effective enough to check surges completely and it does not cross a large enough part of the outlet channels to permit the lowering of the reach below at the beginning of winter.

93. This channel is to be excavated and control dam completed before cofferdams are placed around the improvements for navigation in the south Galop channel. The water should be gradually allowed to enter the diversion as it is shut out of the channel south of Galop island. When the works south of Galop island are unwatered and all excavation is completed, and when the works at Ogden island are in a condition to hold the level of lake Ontario, cofferdams can be removed and the whole works brought into use.

94. The dam, power house and lock at Ogden island are located on the downstream slope of a wide sill of solid rock which crosses the river at about the middle of that island. The main dam, 1,200 feet long, with 19 gates each 50 feet wide and 26 feet deep, is shown at the foot of a diversion channel which is to be excavated through a low part of Ogden island. The discharge capacity of this dam is to be supplemented by additional gates at the downstream end of a power house in the main channel of the river.

95. The channel south of Ogden island is to be enlarged, and a power house 1,300 feet long is to be built across it, near the mouth of Big Sucker creek just east of Waddington. A power house, 3,600 feet long, is shown in the main channel of the river, north of Ogden island.

96. In this project navigation is carried past the dam at Ogden island by making use of the channel south of Ogden island and by a lock on the shore of Ogden island north and east of the power house shown in that channel.

97. The diversion channel is excavated to a bottom elevation of 205 and a width of 500 feet. It is almost entirely in earth. The channel above the power house south of Ogden island is excavated to a bottom elecation of 210 for a width of 800 feet. Some excavation is also shown north of Ogden island.

98. The solid rock surface on which these works are located is about elevation 186. It is intended that the diversion channel, with dam and the enlargement of the channel south of Ogden island, should be completed before the diversion of the flow of the river is begun. For diverting the flow of the river from its main channel a partial cofferdam of rock and a pier and gate structure is proposed on the high rock sill at the head of the rapide Plat. The power house in the channel north of Ogden island has been laid out with 54 units of 5,570 horse-power each at a head of 17 feet. The power house in the channel south of Ogden island has been laid out with 19 units of 5,570 horse-power at a head of 17 feet.

99. The estimates of this project provide for a timber-crib weir to be built below the power house north of Ogden island. It is intended temporarily to hold the tail water level up to about elevation 221, thereby preventing the head from exceeding 21 feet before the dam and power houses at Barnhart island raise the water to its regulated level, which will be about 226 under average summer conditions.

100. In project No. 4-224, the level of the reach above the dam at the head of Barnhart island is to be held to about elevation 224. With this elevation, channel enlargement is required only at a few points. These are indicated on plate No. 29.

101. The dam at the head of Barnhart island is 3,900 feet long. It extends from the head of Barnhart island to the foot of Long Sault island and thence to the high lands on the United States mainland. It is equipped at each end with 11 gates, each 50 feet wide and 21 feet deep. The central part of this dam has a spillway section with crest elevation 224.

102. The United States and Canadian power houses are located at the foot of Barnhart island. The overall length of these two power houses is 3,200 feet. They are shown on a straight line which extends from the above lock No. 20 on the Cornwall Canal to the foot of Barnhart island. North of the Canadian power house there is a retaining wall 400 feet long and north of this a spillway 500 feet long is introduced. To the north of this spillway a lock for 14-foot navigation is shown. This lock is designed to enable the Cornwall canal to be used during the construction period and afterwards. The power houses are to be equipped with a total of 38 units, each capable of developing 47,600 horse-power at 67-foot head. In the power houses proper, submerged or penstock gates provide a discharge capacity of 50,000 cfs. under normal operating conditions. At the south end of the power house 5 sluice gates are provided, each 50 feet wide and 10 feet deep.

103. In this project it is intended to enlarge the narrow channels at the head and foot of Bergen lake and also the narrow parts of the channel between Sheek and Barnhart islands. The total minimum section provided will be 75,000 square feet at elevation 224.

104. The dam at the head of Barnhart island is shown near the foot of Long Sault rapids where the solid rock is found at elevation ranging from 145 to 160. The water at this point is quite swift and elaborate arrangements are necessary to divert the flow in order to unwater the site of the dam.

105. As in the Report of 1921, a diversion channel, 250 feet wide with a grade elevation of 167, is to be excavated through Long Sault island. The sides of the channel are to be lined with concrete to protect them from scour. The westerly end of the main dam crosses the South Sault channel below the entrance of the above diversion channel. The lower part of this section of the dam is to be built before water is let into the diversion channel, and 20 gates, 18 feet wide and 30 feet deep, are to be installed in it. The channel above and below this dam is to be enlarged so that 209,000 cfs. can be passed through the dam with water level above the structure at stage 201.

106. In order to make the diversion effective and maintain present navigation, a timber-crib dam with piers 30 feet wide and 60 feet long, is shown in the river below lock 21 at the head of the Cornwall canal. The openings between these piers are 50 feet wide and by closing the openings the water level at the head of the diversion channel may be raised to elevation 206.

107. This will ensure a diversion of 160,000 cfs. through Long Sault island, 40,000 cfs. down the South Sault channel, and 25,000 cfs. down the Massena canal. It is expected that the diversion of this amount of water from the river, toegther with the control over flow that can be exercised at Galop rapids and at Ogden island by works shown there, will enable the part of the dam which lies in the main river to be built by the ordinary cofferdam method.

108. After the dam in the main channel of the river is completed, the openings left in the section at the foot of the South Sault channel can be filled with concrete, and the timber cut down at Lock 21 will be removed.

109. In this plan No. 4-224, navigation is carried past the dam at the head of Barnhart island by means of a side canal with two lift locks and a pair of protecting guard gates. This canal leaves the raised pool opposite Dickinson Landing and crosses over a saddle in Long Sault island and thence across flat country to a junction with the river at the mouth of the Grass river. Its total length is 6.9 miles. In this length of canal there is one reach 1.0 mile long, and another 1.5 long in which a bottom width of 300 feet is provided.

110. The upper lock in the canal has a 24-foot lift and is located about a mile west of Robinson bay. The lower lock has a lift of about 46 feet and is located near where the canal enters the river north of the mouth of the Grass river. The lock walls of both locks are carried to solid rock which is found at elevation 137 at the upper lock site and elevation 104 at the lower. About one mile above the upper lock, a retaining structure with a pair of guard gates is introduced.

111. A cross-current in the South Sault channel will be prevented by depositing waste material at some point in that channel below the head of the Massena canal.

112. Should it be finally decided to build the main dam in the river at the foot of Barnhart island or at the head of the Little Long Sault rapids above Robinson bay, the side canal could be shortened to the extent of about 2.2 miles by leaving the main river just below the foot of Long Sault island. In this location it could still preserve guard-gate features.

113. The navigation works at and below the Grass River lock in this project are practically the same as in Full Single-Stage project No. 1-242.

114. A concrete intake with gates is to be constructed at the head of the Massena Power Canal as in the Full Single-Stage project No. 1-242. See paragraph 75 of this appendix.

115. In project No. 4-224, some disconnected dykes are shown between the high land west of the village of Wales, and the retaining wall at the north end

of the power houses at Barnhart island. Some dykes are also shown between Richards landing and the guard gates of the proposed canal south of Long Sault island. These dykes are not high.

116. This project does not raise the water level of the river above the general elevation of the surrounding country and abrupt slopes that may develop locally, due to ice conditions in the river, will affect power heads rather than the flow of water through the section.

117. The estimated cost of two-stage project No. 4-224 as presented by the Canadian section is $264,546,000.

118. The head concentrated at Ogden island is small in winter. It can be increased by extensive enlargements of channel between Ogden island and Weavers point. This enlargement is, however, not found to be economical because of the length of restricted channel between these points. The head predicted is vitally dependent upon the ice resistances.

119. Downstream from Ogden island the present slope of the river is 1 foot per mile to Weavers point. Below that point the surface slope is flat and present cross-sectional areas are almost large enough to permit an ice cover to form under natural conditions. Just below the foot of Ogden island at Morrisburg, the lowest points in the solid rock surface fall to about elevation 155 and borings show that this hollow in the rock surface continues downstream to Crysler island. At Crysler island the soft rock of this part of the river is overlain with a layer of sandstone and a narrow sill at about elevation 165 practically crosses the river.

120. At the time the Main Report was signed in November, 1926, this project appeared to be the best two-stage project available. Since that date, additional borings at Crysler island have disclosed more favourable rock foundations than were indicated by the borings made in 1924, and a two-stage project with upper dam and power houses at Crysler island in some major respects appears preferable to the Ogden Island project.

121. Crysler Island Two-Stage Plan. A two-stage project with upper dam at Crysler island and lower dam at Barnhart island is mentioned in the Report of 1921. This project is now presented as an alternative two-stage project, which is regarded by the Canadian section as giving greater financial returns than project No. 4-224, although its initial cost is greater. It will be referred to as project No. 5-217. It is shown on plates 34 to 38. Its estimated cost is $269,355,000. Detail estimates are shown on table 5.

122. The chief works in this project are as follows:—

(1) A free open channel south of Galop island for navigation.
(2) Channel enlargement between Lotus island and Morrisburg to give 95,000 square feet at ordinary levels.
(3) A dam with power house at Crysler island where a head varying from 24 feet in summer to 18.5 feet in winter is developed.
(4) A dam at the head of Barnhart island with power houses at the foot of that island, where a head varying from 60 feet in summer to 56 feet in winter is developed.
(5) A short side canal with lock at Crysler island and a side canal with two locks and a pair of guard gates for carrying navigation past the dam at the head of Barnhart island.
(6) Retaining embankments with pumping and drainage works for preventing the inundation of the village of Iroquois and the town of Morrisburg.

123. The works at Galop rapids for this project are similar to those shown in project No. 4-224, but operate somewhat differently. As in that project

APPENDIX "C" PLATE 34.

the free channel which navigation is to use is located in the channel south of Galop island and occupies its whole length. A large diversion channel is shown through Galop island and channel enlargement is also shown north of Galop island. The dam in the diversion channel is to be equipped with 50 butterfly gates and a similar dam with 16 gates is to take the place of the present embankment between Galop and Adams island. After the works north of Galop island and the diversion are completed, the channel south of Galop island is to be unwatered and the work in that channel is to be done as in project No. 4-224.

124. The works at Galop rapids are designed to pass 310,000 cfs. with a loss of head of 2.75 feet when lake Ontario stands at elevation 246.5. The velocity in navigation channels under these conditions is expected to be 4.7 feet per second. These works could be used for those shown in project No. 1-242.

125. At Iroquois, dykes and pumping works similar to those shown in other projects are required. For the town of Morrisburg, dykes and a pumping plant are provided as in project No. 1-242, but in addition to these works an egg-shaped sewer, 5½ feet high, is to be built north of the dykes between that town and the reach below the dam at Crysler island, a total distance of about 4 miles.

126. At Crysler island, a dam 2,800 feet long is shown on a long curve, with United States and Canadian power houses each 1,500 feet long at either end. This curve is introduced to develop length and follow the most advantageous rock surface. A lock for 14-foot navigation is shown at the Crysler island end of the curved dam. This lock is designed for use until the pond above the dam is raised to above elevation 229 when 14-foot draft will become available in the new canal. Estimates provide for unwatering the control 1,500 feet of the dam at Crysler island by the pneumatic-caisson process and for the unwatering of 700 feet in shallow water by the cellular steel sheetpile trench method. The remainder of the dam and both power-house sites are to be unwatered by the open cofferdam method.

127. The side canal for carrying deep navigation past the dam is shown on the United States side of the river. It is 1.6 miles long and is provided with swing top log apparatus at the head of the lock, as well as duplicate gates and fender chains. The cost of a similar canal on the Canadian side would be substantially the same.

128. Two-stage plan No. 5-217 shows a dam at the head of Barnhart island with power houses at the foot of that island, as in project No. 4-224. The works at the foot of the section are in general similar to the latter project and are located at the same sites. The unwatering problems are the same and it is intended that they should be met in the same way.

129. The water level to be held above the dam at the foot of the section in project No. 5-217 is 7 feet lower than in project No. 4-224. This lower level reduces the lift of the lock in the side canal west of Robinson bay and lowers the bottom elevation of the side canal above that point. This lowering of the reach level also increases the excavation required at the head and foot of Sheek island for the head race.

130. The operation of the Crysler island project presents some difficulty. These are associated with control of flow through the long restricted channel between Butternut island and the foot of Ogden island, just above Morrisburg, when levels on lake Ontario fluctuate. A rise of 2 feet in 4 hours, which sometimes has occurred opposite Prescott, would cause a large increase in flow in restricted channels while the pond between Ogden island and Crysler island, 6,700 acres in extent, is filling up.

131. The travel of surges would not interfere with the use of channels for navigation, as the increased velocities would still be within the limits of safe practice. If, however, a surge should occur in the brief period when an ice park is making upstream past Ogden island, it might increase velocities beyond 2.35 feet per second. Should the river surface be heavily burdened with ice at this time, a gorge might occur.

132. This contingency is met in the design of works at Galop island, now described with the Crysler island project, by the provision of gates for quickly throttling the flow. A somewhat similar design could be included in the full single-stage project 1-242, at some increase in cost.

133. A series of cribs with boom is provided above point Three Points and a similar boom is provided above Butternut island. These booms would start an ice park at these points. They would be swung by tugs after the close of navigation each year and they would melt free from the ice and swing clear in the spring when released. The use of all of the above agencies should prevent gorging of any magnitude taking place with the channel enlargement shown in the project.

134. Since the power plants at Crysler island can be completed and put in operation about two years before the works at Barnhart island can be completed, the Crysler island development is designed to operate at 34-foot head until the time when the lower level is raised. In this way about 760,000 horse-power could be made available before the lower plant is completed. This project initially furnishes about 300,000 horse-power more than project No. 4-224 in the upper stage. Computations also show that the completed project No. 5-217 will produce about 10,000 horse-power more than the Ogden island project No. 4-224 during winter.

135. Partial Single-Stage Plan. A single-stage scheme, with lock and dam control at Galop rapids and a controlled level of the reach above Barnhart island, has been considered. The Report of 1921 presented a somewhat similar project. It showed a control dam and lock at Ogden island combined with a lower pool at about elevation 231. In the designs of this project, provision was made for a future rise of seven feet in the crest of the lower dam, if ice conditions permitted such a rise to be made with safety.

136. In the Report of 1921 no mention is made of channel enlargement being necessary when the raise to higher levels in the Long Sault was to be brought about. Progressive enlargement could be made with the control dam and lock as shown in that project.

137. The present Board finds, as stated previously, that the initial project described in the Report of 1921 should be modified to secure more dependable winter operation and develop more power. The Board also finds the size of channels provided in the project of 1921 to be too small to form an ice cover between the foot of Galop island and the foot of Ogden island and enlargement to greater dimensions is necessary to reduce frazil formation and insure more dependable flows in winter. When this enlargement is made and slopes are flattened, higher levels can be carried in the lower pool. Changes such as these might be progressively made up to the point where the full elevation provided in the project of 1921 would be made practicable. Such a project might be worked out with control dam and lock at Ogden island as shown in the report of 1921, or it might be worked out with similar control works at Galop rapids. Comparative estimates for such a project show a slight advantage for control works at Galop rapids when the lower reach is held above elevation 235.

138. In order to show the operating characteristics of a single-stage project giving about the same results as that visualized in the Report of 1921, a project

with lock and dam at Galop rapids and crest level of 238 at Long Sault dam has been worked out. It will be referred to here as No. 6-238. It is shown on plates No. 39 to 43. Detailed estimates will be found on table No. 6.

139. The channel shown in this project is enlarged to 65,000 square feet in Galop rapids and to 95,000 square feet below. This is the same enlargement as that shown in the Crysler island project and is about the same as that shown in full single-stage scheme No. 1-242.

140. In this scheme (No. 6-238) a control dam is placed at the Galop rapids and the dam at the lower end of the section is shown at the head of Barnhart island, and the channel between Sheek and Barnhart islands is used for the headrace of the power houses at the foot of Barnhart island. This channel is to be enlarged so as to give about 87,000 square feet at elevation 238.

141. The computed head concentrated at the control dam is shown on plates 44 and 45. It would vary from month to month with the level on lake Ontario and the discharge.

142. The estimated cost of this project is stated by the Canadian section to be $228,610,000.

143. In this scheme nearly, if not all, the gates in the Galop control dam would be open during flood conditions and during the latter part of the ice-covered period. During the low-flow periods of late summer and autumn some control gates would be closed.

144. The control of flow out of lake Ontario would be governed in part by the level of the Long Sault reach and in part by the opening and closing of gates at the Galop Rapids dam. With this scheme an ice cover would pack upstream from below Ogden island without gorging of the section so long as the flow out of lake Ontario is held down to about 203,000 cfs. and the water level at the long Sault is held up to about elevation 239.

145. A dam is shown across a diversion channel at Galop island and also across a channel on either side of a lock at Lotus Island. The latter would control the flow south of Galop island. A gated house is shown in both dams, with butterfly valves for the bulk of the openings instead of roller gates. Early in the winter there would be a head of two or three feet at the south Galop control dam and a head of three to four feet would be used up in the slopes and dam of the north Galop channels. The head in the north Galop channel together with ability to quickly close gates in the other channels can be used to prevent excess flows passing the section during surges.

146. The above-described scheme would develop all the head available in the section during the winter period, and also all that available in summer when lake Ontario is near extreme high and extreme low stages. The amount of power not developed by this project is greatest in the open-water period when lake Ontario stands about elevation 246·0. At that time the head lost would be about 3·5 feet.

147. The control of velocity of flow in restricted channels afforded by this project is better than in other schemes because fewer gates need be opened or closed to increase or decrease the flow in the river, and the distribution of flow in channels can be better controlled. It imposes a guard lock in the path of navigation instead of the navigable pass shown in the full single-stage project.

Improvement for Navigation Alone

148. The river is now actually navigated by all traffic through the four-mile reach between Iroquois and the head of the Morrisburg canal, through the ten-mile reach between Morrisburg and the head of Farran Point canal, and through the four-mile reach between Farran Point and the head of the Cornwall

Canal. The vessels used in this navigation are, however, heavily powered in proportion to their size. The only parts of this section of the river, above Cornwall island, regarded as safely and conveniently navigable in its present condition by large lake freighters and ocean vessels are the four-mile reach from Weavers Point to the Farran Point rapids, and the four-mile reach from the foot of the latter rapids to the entrance to the Cornwall canal.

149. The entire reach of river from Morrisburg to the head of the Cornwall canal can be rendered safely navigable for deep-craft vessels with a moderate amount of dredging if the water level be raised to elevation 220. At this elevation the flowage damage is not extensive. The plans for improving the river for navigation alone provide, therefore, for raising this reach by a series of dams across the head of the Long Sault rapids.

150. The plans provide a large discharge capacity through the gates of these dams, so that the pool created can be drawn down in winter, with a view to avoiding, ordinarily, the formation of ice jams in the reaches between Morrisburg and the dams, and of holding the rise consequent to such jams to minimum levels. Under no circumstances could the back-water from such rises affect the discharge capacity of the control section at the Galop.

151. Above Ogden island, a lateral canal is a cheaper means for affording navigation than is the ponding of the river, and the ponding offers complications in assuring the winter discharge capacity. The plans for navigation alone provide, therefore, for a lateral canal on the United States shore through the upper part of the section.

152. In detail, the plans provide for the enlargement of the channel at Chimney point on the same lines as is proposed in the two schemes for combined navigation and power development. The dyke at the head of the north channel is to be left in place. The material excavated can be so deposited as to compensate for the effect of the enlargement on the levels of lake Ontario.

153. Navigation enters the upper canal at a guard lock on the United States shore opposite the head of Galop island. The sills are at elevation 211, coping at 253. Service gates are in duplicate, unwatering gates are provided at both ends of the lock outside of the service gates, and an emergency dam is also provided. Adjacent to the lock is a weir with three gates, 20 feet in width, with sills at elevation 230, to provide the supply of water for maintaining the canal levels.

154. The canal follows close to the shore, and is formed partly in cut and partly by retaining embankments at indentations in the shore, to a point opposite Lotus island. It then cuts across the peninsula of which Sparrowhawk point is the projecting tip, thence follows generally the shore to the bay above Point Rockway. It then follows the swale back of that point, cuts across the base of Leishman point, and enters the south channel of the river at Ogden island. Suitable embankments across the entrance to this channel at the head of the island, and on the island itself, permit the water to be raised to the canal level, at elevation 241. The total length of the upper canal is 12·5 miles, of which 1·5 miles is through the pool formed in the south channel at Ogden island.

155. Navigation is carried from the canal to the river pool by a lock at Ogden island, opposite Waddington. The upper gate sills of this lock are at elevation 211, lower gate sills at elevation 190, main coping 246. Service gates are provided in duplicate, with unwatering gates outside of the service gates, but no emergency dam is provided, since in case of accident the canal can be drawn down. A weir extends from the lock to the United States shore. This weir has 20 openings, each 15 feet in width, with sills at elevation 236. Stop logs in these openings provide control of the canal levels.

156. The river channels from the lock to the head of the lower canal, at Long Sault island, are excavated to a minimum width of 450 feet, and to grade 196 at the head of the pool, ranging down to 195 at the foot of the pool.

157. Navigation enters the lower canal through a cut across Long Sault island, with a bottom width of 200 feet at the summit cut; it crosses the South Sault channel, and is carried down to the main canal level through a lock on the United States shore about one mile inland. The upper sills of this lock are at elevation 190, lower sills at elevation 170, main coping at elevation 229. Service gates are in duplicate, with unwatering gates outside of the service gates, and an emergency dam is provided.

158. From this lock navigation passes through a canal, 4·6 miles in length, to a lock near the mouth of the Grass river. The normal operating level of this canal is at elevation 200. Navigation is carried down to the south channel of the river at Cornwall island by a lock similar to that proposed in the combined navigation and power developments, the upper sill being at elevation 170 and coping at elevation 205.

159. An earth dyke and a waterway are constructed at the Grass River lock, as with the combined navigation and power developments, and the same measures are taken to prevent floods from the Grass river from interfering with the approach to the lock.

160. The total length of the lower canal, from the north shore of Long Sault island to the head of the south Cornwall channel, is 7·1 miles.

161. The total length of restricted canal navigation throughout the section is 18 miles.

162. The Ottawa branch of the New York Central railroad is to be diverted to a crossing adjacent to the Grass river lock as in the combined navigation and power development.

163. The estimates show considerably less enlargement of the south Cornwall channel than is proposed in the combined navigation and power project, on account of the steadier flow without power development.

164. The dams creating the navigable pool which extends from Long Sault island to Ogden island are three in number; one across the main river channel, one across the diversion channel proposed to facilitate the unwatering of the main channel, and one across the South Sault.

165. The dam across the main channel is located just above the head of the Long Sault rapids, and is 1,545 feet in length. It is provided with 24 Stoney crest gates, each 50 feet in width, with sills at elevation 195. Construction must be so prosecuted as not to interfere with present navigation through the Cornwall canal, the final closure being made during the winter season. The diversion cut across Long Sault island, to facilitate the unwatering of this dam site, is of the same dimensions as is proposed in connection with the unwatering of a dam for navigation and power at the foot of the rapids. It is to be closed by 20 sluices, each 15 feet in width by 30 feet in height, with sills at elevation 165, which will be submerged after the pool is raised. The dam across the South Sault is 375 feet in length, with 6 crest gates, 50 feet in width, with sills at elevation 195.

166. The plans provide head gates at the entrance to the Massena power canal, as in the combined navigation and power schemes. A few low dykes are required along the United States shore opposite Long Sault island, and a dyke is required on the Canadian shore at the head of the swale that parallels the river eastward from Hoople creek.

167. The estimated cost of this project is $79,000,000. Detailed estimates are shown in Table 7.

LAKE ST. FRANCIS SECTION

168. This section of the St. Lawrence river covers in general the expansion of lake St. Francis. It may be taken as extending from Colquhoun island opposite St. Regis, mile 115, to deep water at the foot of lake St. Francis, mile 141, a distance of 26 miles. It embraces almost the same stretch of river as Division No. 3 in the Report of 1921.

169. Lake St. Francis is an area of water which lies between very low flat shores. It appears to be formed from a number of delta-like channels with banks submerged about three feet at the westerly end, ten feet in the middle, and sixteen feet at the easterly end of the lake. The present depth in these channels is more than is required for 25 foot navigation in all but a few places, and the natural alignment of these submerged channels is so good that navigation can quite well follow them. The fall in the lake from Colquhoun Island to Coteau Landing is about one foot at mean flow.

170. Beyond the immediate shores of the lake the country is low and flat and consists of layers of peat overlying clay. These flats when drained subside and burn so that now we find great areas south-east of the Hungry Bay and St. Barbe dykes at about the level of Lake St. Francis. These areas are dependent for drainage on ditches which lead sometimes to the lake and sometimes away from it. Originally a very low flat peat covered divide separated the drainage area of Lake St. Francis from that of the St. Louis River leading into Lake St. Louis. With dyking, drainage and cultivation of country no divide now exists except the Hungry Bay and St. Barbe dykes. These are the structures which prevent the waters of Lake St. Francis from finding their way to Lake St. Louis via the lowered peat lands and the St. Louis River.

171. As a consequence of these conditions the water level of lake St. Francis cannot be raised above that to which it would go in nature. In fact the dykes as now existing are not high enough to retain the high water levels of 1862-1870-1886 and 1887 should they recur, and some raising of these must be undertaken no matter what action is taken regarding the improvement of the section for deep water navigation.

172. Lake St. Francis has a superficial area of about 90 square miles; it has a cross-sectional area of 460,000 square feet near its foot, 260,000 square feet at McKee's point near its middle and about 160,000 square feet between Colquhoun island and Hamilton island at its head. In the Hungry bay section of the lake St. Francis, the movement of the water is sluggish and it cools down and freezes over before it freezes in other parts of this lake. In the swiftest flowing parts of the lake the average velocity of the water is less than 2.0 feet per second, and as a consequence a week of zero weather can be depended upon to form a smooth ice cover over the whole of the lake without much packing or jamming of the surface.

173. In order to provide a depth of 25 feet for a width of 450 feet, it is necessary to remove projecting points at eight places between St. Regis Island and Butternut Island and also to excavate a channel 2,000 feet long opposite the village of Lancaster. The project plane for this section is 150.5 at the foot of the lake.

174. The work recommended to be done in this section is shown on Plates 46 to 48. Estimated cost of this work is $980,000, details of which are shown in table No. 8.

175. The general features and alignment of navigation channels shown on the Board's plans in this section are substantially the same as those recommended in the Report of 1921.

SOULANGES SECTION

176. Description.—This section of the St. Lawrence river is 18 miles long and extends from deep water at the foot of lake St. Francis, mile 141, to deep water at the head of lake St. Louis, mile 159. The mean level of the water in lake St. Francis at the head of the section is elevation 151.9, and that in lake St. Louis, at the foot of the section is 68.9. The total drop in the section is 83 feet. This, the river takes in four more or less abrupt chutes, vix, the Coteau, Cedars, Split Rock, and Cascades rapids. Of this fall, 3.0 feet occurs between the Lake St. Francis and Leonard Island, 14.3 feet in the Coteau Rapids, 6.6 feet in the river between the Coteau du Lac Wharf and Isle Aux Vacres, 32 feet in Cedars Rapids, 8.1 feet between the Cedars power plant and Bisson Pt., and 19 feet between Bisson Pt. and Lake St. Louis, in what is called the Split Rock and Cascades Rapids.

177. Upstream navigation through the Cedars and Cascades Rapids is impossible and the only boats that navigate the open river on the downstream journey are the special passenger boats operated for the tourist trade. All freight boats use the present Soulanges Canal which provides for ships of 14 foot draft, and extends from Coteau Landing on Lake St. Francis to Cascades Point on Lake St. Louis. This canal is 100 feet wide on the bottom, 15 feet deep and 14 miles long. It has one guard lock at Coteau Landing and four separate locks near its lower end just above where it enters Lake St. Louis. This canal crosses three small rivers, a short distance north and east of Coteau du Lac. Power for operation of this canal is supplied from a station of its own at the mouth of the River a La Graisse, where a head of about 20 feet between the canal and the river at that point is utilized.

178. In this section of the St. Lawrence river there are four power developments now in operation. Three of these are located at the foot of Cedars rapids and one is located in the city of Valleyfield on a side channel of the St. Lawrence south of Grande isle. The largest of the power plants in the section is the Cedars Rapids plant, owned and operated by the Montreal Light, Heat and Power Consolidated. It has an installed capacity of 197,000 horse-power at a 32 foot head.

179. The next largest plant is the St. Timothee plant of the Canadian Light and Power Co., with a practicable capacity of about 22,000 horse-power. The Canadian Light and Power Company is now understood to be affiliated with the Montreal Light, Heat and Power Consolidated. This plant draws its water supply from an old abandoned navigation canal and operates under about a fifty foot head.

180. The third largest plant in this section is the Provincial Power Plant which is owned by the Montreal Light, Heat and Power Consolidated. It has a practicable capacity of 12,000 horse-power and draws its water supply from the Soulanges Canal. It operates under a head of about 52 feet.

181. The fourth development of importance is at Valleyfield and consists of a group of plants largely owned by the Montreal Cotton Co. This group uses about 10,000 cfs. at a head of about 11 feet. The output may be taken at about 10,000 horse-power, all of which power is used in the adjacent mills and city. The head at this point was originally created by a dam built by the Canadian Federal Government in 1849, for the improvement of navigation in the entrance to the Beauharnois canal. The power works now in existence at Valleyfield have been brought about by a series of plant extensions extending over half a century.

182. The country on either side of the river between Lake St. Francis and Lake St. Louis is generally flat and uniform except where boulder clay ridges rise through the marine clay which generally covers the country. A large area of territory south of St. Timothee and north of the St. Louis river is occupied by these ridges but in a few places passes are left, through which the marine clay plain is continuous.

183. South of the boulder clay outcrops above described, the country slopes to the St. Louis river, but there are no creeks or water courses because the area drained is small.

184. In the Soulanges Section, solid rock outcrops in many places and it does not appear to be far below the bed of the river throughout the section. It forms the bed of the river in the Coteau, Cedars, and Cascades rapids and can be seen at many points in the country north and south of the city of Valleyfield. It is exposed on the south side in the St. Louis river, five miles east of lake St. Francis, and on the sloping hillside at Melocheville. On the north side of the river it is exposed at Coteau du Lac, in Chamberry Gully and all along the river from Cedars to Cascades Point.

185. The chief urban centre in the section is Valleyfield, population 10,000. It is situated on a small outlet of lake St. Francis on the south side of Grande Ile. The ground level of this city is from 5 to 10 feet above the level of lake St. Francis.

186. Other villages to be noted in this section are Coteau du Lac, Cedars and St. Timothee. Coteau du Lac, population 485, is on the north side of the St. Lawrence river about 3 miles below lake St. Francis near the foot of Coteau Rapids where the DeLisle river comes into the St. Lawrence from the north. Its ground level is about the elevation of lake St. Francis. The village of Cedars, population 536, is located on the north side of the river at the head of Cedars Rapids. Its ground level is about ten feet below the elevation of lake St. Francis. The village of St. Timothee, population 450, is located a little below Cedars on the south side of the river. Its ground level is about 25 feet below the level of lake St. Francis.

187. The floor of the river in Coteau rapids is crystalline limestone of a specially hard gritty nature. That in Cedars Rapids is dolomite, and that in the Cascades rapids is Potsdam sandstone.

188. At the present time the river runs open in the winter throughout this whole section, from the foot of lake St. Francis to the head of lake St. Louis. In this distance fourteen square miles of water surface is exposed to the cooling influence of the air, and about 240,000,000 cubic yards of frazil is formed each winter. This is stowed under the ice cover at the head of lake St. Louis and produces a winter rise of from 10 to 15 feet in the water level at the foot of Cascades rapids near Melocheville.

189. *Proposed Plan of Improvement.* As shown in paragraphs 163 to 169 of the Main Report, the Board finds it practical and economical to combine improvement for navigation in the Soulanges section with improvement for power. It also finds that a combined river and overland canal project, considering interest charges, gives greater economy than any other joint navigation and power project investigated. As stated in paragraph 175 of the Main Report, this project " better provides for the present and future development of the waterway than any scheme for navigation alone, and is therefore the desirable scheme, if arrangements are made whereby power interests bear a fair proportion of the cost of the initial expenditure required." This project is called the Ile aux Vaches Three Stage Project for navigation and power. It is shown on plates 49 to 51. Its estimated cost is $103,945,000. Detailed estimates are given on tables 9 and 10.

190. This project is similar in form to the "Cascades Point—Coteau Rapids Project" described in the Report of 1921, but its details are changed in some respects. The power features of this project are planned to be developed in three successive stages.

191. The works comprised in the navigation project and in the first stage of the development for power are as follows:—

(*a*) A short submarine channel, 450 feet wide and protected by breakwaters, leading from deep water in lake St. Francis to the north shore of the river at Coteau Landing.

(*b*) An overland canal, 12,500 feet long and 200 feet wide, extending from the shore of the St. Lawrence river at Coteau Landing to the mouth of the DeLisle river.

(*c*) A lock at the east end of this canal with lift of from 1 to 5 feet, dependupon the stage of the lake, along with an approach channel leading into what will be deep water in a Coteau du Lac-Cedars pool.

(*d*) A dam across the St. Lawrence river extending from above Cedars village to Point du Domaine on Grande ile which is virtually the south shore of the river. This dam is to control the level of lake St. Francis and is to be connected with a power house at Ile aux Vaches and Ile Juillet capable of developing 382,000 horse-power at a head of about 22 feet. Embankments are provided to protect the low lands on both sides of the river.

(*e*) An enlargement of the river at Coteau Rapids so as to enable the level of lake St. Francis to be extended to a pool below Coteau du Lac with a loss of head of not more than 1½ feet in periods of low discharge, and not more than 5 feet in periods of extreme flood. This is to be done by means of an enlargement at Round island and a long diversion channel, 240 feet wide on the bottom with grade Elev. 120, separate from the river and extending from above Clarke island to below Broad island, a distance of about 2½ miles. The flow through this diversion channel can be controlled by means of 13-50 ft. gates, 20 feet deep.

(*f*) A side canal from the shore of the river above Cedars to the Ottawa arm of lake St. Louis, north of the outlet of Chamberry gully, along with a submarine channel leading out into lake St. Louis.

(*g*) A pair of guard gates in the middle of this canal with two lift locks near its easterly end. One of the locks is located a short distance west of the point where the canal crosses Chamberry gully and the other is located near the shore of lake St. Louis. The locks in this side canal are designed to overcome a total difference in level of 80 feet.

(*h*) Such drainage and diversion works as are required to protect the villages of Coteau Junction and Coteau du Lac and the valleys of the Delisle, Rouge and A la Graisse rivers from the raised levels of the river.

192. The works comprised in the second stage of the improvement have to do with power entirely. They are as follows:—

(*a*) A head race canal from above Cedars village to the Ottawa arm of lake St. Louis with a power plant at the mouth of Chamberry gully capable of developing 500,000 h.p. at a head of 75 feet, with embankments, bridges, extension of syphon culverts and other works required to make available the 500,000 h.p. at that point, less 12,000 h.p. to be put out of commission at the provincial plant near Cedars.

193. The works comprised in the third stage of the development have also to do only with power. They are as follows:—

(*a*) A dam across the St. Lawrence river a short distance above the village of Melocheville. This dam to be connected with a power plant on the shore of lake St. Louis north of Cascades island, capable of developing 974,000 h.p. at a head of 53 feet, but will put 212,000 h.p. out of commission at Cedars and St. Timothee.

(*b*) A new road on the south side of the river from above the village of St. Timothee to Melocheville, and such other works as are necessary to adjust the community to a raised level of elevation 125 in the reach between Cedars and Melocheville.

194. *Economic Considerations.* The determination of the best method of improving a river in which power resources are to be developed depends partly upon the physical cost of improvement by various schemes and partly upon the rate at which power resources if made available, can be absorbed.

195. Statistics show that the province of Quebec west of Quebec city has been absorbing power at the rate of 250,000,000 kilowatt hours per year for the past six years. This is exclusive of power used in electric steam boilers which is generally off-peak power. This is equivalent to about 72,000 horse-power peak load growth per year at 50 per cent load factor. Some of the territory included in the above district is not tributary to the St. Lawrence and unless all distributing companies are prepared to exchange power it cannot be expected that all power needs for any period can come from the St. Lawrence.

196. Recently the Water Power Branch of the Canadian Department of the Interior predicted a growth in installed capacity of power plants in the St. Lawrence basin, of 225,000 horse-power per year. According to factors which they have developed, this would mean a growth of about 150,000 horse-power per year in base load plants such as those on the St. Lawrence river. It appears reasonable to take half of this growth as in Quebec and half in Ontario as the amount of power in use in these two provinces is about the same.

197. The annual growth in simultaneous peaks of the power systems now connected in the Montreal, Eastern Townships and Quebec districts, is about 50,000 horse-power and until the cheap power now undeveloped on the Ottawa and on its tributary streams is put to use, it is not likely that the whole province west of Quebec city will draw the additional power it needs from any one source.

198. After all cheap power sites are developed and after all the power on the International section of the St. Lawrence is put to use, the rate of absorption from the Quebec section of the St. Lawrence will probably be much greater. A rate of absorption in Canada of at least 150,000 horse-power per year for this St. Lawrence power fifteen years hence is not unreasonable.

199. In order to give an idea of the overall cost of various projects, rates of absorption of 40,000 horse-power, 75,000 horse-power, and 150,000 horse-power are taken and 5 per cent per year is added to the first cost to cover interest during half the construction period and during half the period required to market power, as derived from the above rates of absorption. The results are shown on tables Nos. 11 to 13 and 29.

200. The Soulanges section offers many opportunities for variation in designs of projects but analysis shows that those projects which can be executed in successive stages bring about greater economy than projects which require all the works connected with them to be constructed at one time.

201. A feature of the Ile aux Vaches Three Stage project which makes it more economical than any other, having in view the interest of both navigation and power, is the fact that through navigation may be secured on an economical general plan with the first stage of the power development without any expenditure for stages two and three, and without interference with the operation of the present Cedars plant.

202. The side canal between Cedars and lake St. Louis is designed so that some excavation made for it may be of use in connection with power development in stage two. This is done by joining the alignments of the power and navigation canals about two miles east of Cedars village.

203. The estimated cost of this complete project including the power works of stages two and three is $205,052,000. The first stage is estimated to cost $103,945,000. In the latter amount $11,821,000 is for a side canal from lake St. Francis to Coteau du Lac; $19,773,000 is for a side canal between Cedars and lake St. Louis; $9,212,000 is for the enlargement of Coteau rapids and the reduction of open water at that point; $38,553,000 is for the dam and power house substructures at Cedars along with embankments and drainage works required to raise the water level of the river to complete the improvement for navigation. $101,107,000 is for the work in Stages two and three.

204. The Ile aux Vaches Three Stage Project for navigation and power above described, involves the removal of the northerly part of the village of Cedars and the dyking of the village of Coteau du Lac in the first stage of improvement. It also requires the inundation of part of the village of St. Timothee and the removal of the present Cedars plant in the third stage of improvement. It requires the use of extensive dykes along the north shore of the river between Coteau du Lac and Cedars and along both sides of the navigation improvement between Cedars and Cascades Point, as well as the use of some embankments between point du Domaine on Grande ile and the high land northwest of the city of Valleyfield.

205. The project is designed to pass maximum floods without raising the level of Lake St. Francis higher than it would go under natural conditions. It is designed so as not to retard the flow in winter. It is designed so as to secure a complete ice cover from Lake St. Francics to the Coteau Bridge, and also from the foot of Broad Island to the dam to be constructed at ile aux Vaches. It is designed to secure an ice cover in the head race canal between Cedars and Chamberry gully which is part of the second stage of the improvement, and also an almost complete ice cover from ile aux Vaches to the dam at Cascades island when the works described for the third stage are built.

206. The water surface areas which are expected to remain open in winter when the improvement of the section is complete, are confined to: a stretch of river about 11,000 feet long between the present Coteau bridge and Coteau du Lac; a diversion channel varying in width from 270 to 670 feet, and extending from Clarke island to the foot of Broad island; a short stretch of river immediately below the proposed power plants at Ile aux Vaches and below the proposed dam in Cascades rapids.

207. A lock in the side canal between Coteau Landing and Coteau du Lac is included in the plan. If there were no lock at this point, the canal would have to be 700 feet wide to give satisfactory navigation velocities. This wide channel would cost about $16,000,000. A velocity of 4½ feet per second in a navigation channel is not low enough for an approach to a draw bridge, and if the lock in this canal is done away with, an extra expenditure of about $5,000,000 would be required for a new bridge in quieter water. A deduction of $2,600,000 from this $21,000,000 could be made if no lock is built, making an increased expenditure of $18,400,000. As the extra power created by the wider channels

and the time saved to initial navigation will probably not justify the extra expenditure involved, open river navigation at this point is not included in the initial project at this time.

208. Much consideration has been given to the relative advantages of single and flight locks at the foot of the overland canal between Cedars Village and the Ottawa Arm of lake St. Louis. Comparative estimates show no material advantage for either type of improvement and the conclusion is that either may be used without loss of efficiency or economy. Single locks are provided for in plans and estimates.

209. A number of locations for the power house on the ile aux Vaches dam are available. Estimates show no material difference in cost of these and the plans filed can be varied in this regard.

210. A difficult feature of the ile aux Vaches project is the improvement of Coteau rapids so as to permit the raising of the Cedars pool to the height desired, without interfering with flood levels on lake St. Francis and without introducing ice jams that would endanger the continuity of the winter flow of the river. The plan of improvement shown at Coteau rapids consists in an enlargement of the river at Round Island and in the excavation of a deep smooth diversion channel, separate and distinct from the river, from above Clarke island to below Broad island. To simplify the bridging of the diversion channel, the line of the Canadian National Railway is relocated in the vicinity of Bellerive. The diversion channel is designed to divert about 52,000 c.f.s. under winter conditions. It will reduce the velocity in the river above Coteau Bridge to 1.86 feet per second with a winter flow of 230,000 c.f.s. and thereby assist in firmly holding the foot of the ice cover at the Coteau Bridge throughout the winter. This will leave the area of exposed water surface at the head of the Coteau du Lac-Cedars pool at about 45,000,000 square feet or 1.6 square miles, and about 13,000,000 cubic yards of frazil may be expected to form. As the cross-sectional area of the river just below Coteau du Lac at elevation 147 is about 145,000 square feet and as the flowing water will only occupy about 65,000 square feet, after the pack is formed, this volume of slush and frazil will create a pack about 4,400 feet long. From many observations in other sections of the St. Lawrence, it is predicted that the loss in head in January and February from this cause will vary from 1 to 2 feet, depending upon the weather.

211. The sectional areas of the overland power canal between Cedars and Chamberry gully, under the second stage, is made of such dimensions that 500,000 horse-power can be developed at Chamberry gully without velocities greater than 2.25 feet per second being set up. This will permit an ice cover to form in this canal.

212. The third stage of the Ile aux Vaches scheme for the development of power at Cascades contemplates the raising of the water surface in the Cedars rapids to a point where the average velocity of the water will be about 2.7 feet per second from the power house at Ile aux Vaches to the village of St. Timothee. This velocity is believed to be low enough to permit an ice pack to work upstream without any large quantity of frazil being carried underneath the ice cover and as a consequence no great rise of water level in the tail-race of the Ile aux Vaches plants is expected in winter.

213. An important feature in the improvement of this section is the existence of the 197,000 horse-power plant now operated by the Montreal Light, Heat and Power Consolidated, at the foot of Cedars rapids. As has been explained this plant now utilizes a head of 32 feet in the middle of a series of rapids having a total fall of 83 feet. This plant has operating difficulties on account of ice conditions.

214. The third stage of the Ile aux Vaches development involves scrapping this plant, but all the excavation now done in the head-race and in the river will be utilized.

215. In an effort to use this plant, a three stage river development with side canals as in the Ile aux Vaches project has been considered. The first step of this improvement would be a plant with a 22 foot head at Ile aux Vaches, the second step a plant with a 32 foot head at Cedars and the third, a plant with a 20 foot head at Cascades island, all utilizing the complete flow of the river.

216. This scheme would treat the river above Ile aux Vaches from a hydraulic point of view in the same way as the Ile aux Vaches scheme, and it would preserve water levels above and below the present Cedars plant. In the designing of this kind of a scheme no difficulty is found in securing a good operating proposition in summer, but in winter a length of 7½ miles between ile aux Vaches and lake St. Louis will run open and would form 120,000,000 cubic yards of frazil and slush ice which must be stored somewhere. The bulk of this may accumulate as it does now, at the head of lake St. Louis, in which case the operating head of the power plant at Cascades would lose about 10 feet and its output would be reduced by about 250,000 horse-power. On the other hand if this ice be accumulated above the Cascades Island power house and dam, as is probable, the old and new power plants at Cedars would have their operating head reduced to one-half that now utilized with a loss of power amounting to about 360,000 horse-power.

217. Such a project cannot economically be improved by dredging on account of the enormous yardage, a large part of which is rock, that has to be removed to make the project workable in winter. This scheme, therefore, is out of the question from an operating and financial point of view.

218. A scheme to improve the river for power, making only partial use of the present Cedars plant, was also considered. It involves the building of a new power plant just north and east of the Cedars plant, to serve present customers while the old plant is being rebuilt to utilize a higher head. This scheme requires power plants at Cedars to operate for a time at one tail water level and afterwards at a tail water level ten feet higher. This is not a desirable feature but it was thought to be a practical solution provided 33 per cent of the flow be diverted from the river at this point and used to develop power directly from a power canal at Chamberry under a head of 78 feet. Analysis of this scheme showed its first and also its overall cost to be more than the Ile aux Vaches three-stage scheme, and as it has no operating advantages over that scheme, it need not be further considered.

219. If there were a large market for power and no vested interests in the river, the best scheme of improvement for both power and navigation would be an all river project with the reaches between Coteau du Lac and Cedars and between St. Timothee and Melocheville used as navigation pools. For such a project the level of the lower reach must be raised to at least elevation 115 in order to escape expensive submarine excavation between Cedars and Melocheville. It is shown on plates 52 and 53. Detailed estimates are given in tables 18 to 20. Its estimated cost is $194,317,000.

220. This project, with power houses at Cedars and at Cascades, involves the raising of the whole river between Coteau and Cascades about 20 feet at the same time unless power is secured elsewhere to supply Cedars customers while the development is being made. This requires the building of one-third of the Cascades Island plant as a first part of the first-stage of the project, then installing machinery in a new power plant at Cedars as the other

part of the first stage. It involves reconstructing the present Cedars plant as the second stage and completing the Cascades Island development as the third stage of the project. This scheme proposes to take care of the present Cedars customers by transferring load to the first part of the Cascades Island development early in the spring of some selected year and then arranging during the succeeding summer for the cofferdamming of the present Cedars plant and the raising of the upper reach before the advent of the winter ice. The hazards connected with the operating of this scheme during construction would be serious.

221. When interest is considered and a growth of 75,000 horse-power is assumed, this scheme shows about the same overall economy as the Ile aux Vaches project. It would, however, in the first stage of its construction interfere with the present Cedars plant and would require a very large expenditure before any power would be produced.

222. Another project which was considered was a simple two-stage scheme with a 22 foot initial development for power opposite point a Biron, a short distance above Ile aux Vaches. Incorporated with this, was a 54 foot development at Cascades island. This scheme utilized the investment in the Cedars Rapids head-race, but required the removal of the Cedars building itself when the 54 foot plant at Cascades island would go into commission in the second stage of the improvement. It is shown on plates 54 and 55. Its estimated cost is $203,692,000. Detailed estimates are shown on tables 21 and 22.

223. This method of developing the power in the river would leave the valley of Chamberry gully free to be occupied by navigation works as there would be no power development at Chamberry gully and no overland power canal between Cedars and that point. The first cost of this project is $1,360,000 less than the Ile aux Vaches three-stage project, but the overall cost on the assumed growth of the power demand, is much greater due to the necessary execution of the work in two stages instead of three.

224. Another scheme which has carefully been considered is the improvement of the river for navigation and power by means of an enlarged side canal between Hungry bay and Melocheville, this work to be coupled with a river development so as to give a 4-stage power development. The first stage of this scheme consists in building a canal between Hungry bay and Melocheville and developing a certain amount of power at a 78 foot head at Melocheville. It is shown on plates 56 and 57. There would be a guard lock at Hungry bay and double flight locks at Melocheville for deep navigation as in the project recommended in the Report of 1921 together with bridges, and channels in Lake St. Francis and Lake St. Louis as in that project. The second stage of this proposition consists in developing 370,000 horse-power at Ile aux Vaches above Cedars as in the Ile aux Vaches scheme. The third stage consists in the development of a certain amount of power at a head of 78 feet at Chamberry gully. The fourth stage develops the same amount of power at Cascades island as is developed in the Ile aux Vaches scheme.

225. In this scheme of development, the capacity of the first and third stages can be varied between wide limits but the size of the second and fourth stages must remain constant as river channels planned will cover with ice only when the flow in them is limited to set amounts.

226. In order to show the effect of improving the river in the above manner, the Hungry bay-Melocheville canal has been laid out with a width of 300 feet, 400 feet and 930 feet, and with capacities of 15,500 cfs., 31,600 cfs., and 66,700 cfs. exclusive of the water required for navigation. The total net cost of

improving the whole section by each of these variations is $213,509,000, $223,-533,000 and $237,778,000 respectively. Detailed estimates with 31,600 cfs. diverted are shown on table 25.

227. In the first case the average velocity of the water in the canal is taken at 2.0 feet per second. In the others it is taken at 2.25 feet per second. Analysis of the above costs shows that the development of power by means of the smallest diversion is more economical than by the larger diversions. All developments with power at Melocheville are more costly than by the recommended project. (See tables 26 to 29.)

Improvement of Soulanges Section for Navigation Alone

228. If an improvement solely for navigation is desired one way it can be secured is by building an overland side canal from deep water in lake St. Francis via Hungry bay and the low flat uniform country north of the St. Louis river to the head of lake St. Louis at Melocheville.

229. An improvement of this kind has been laid out. It has double locks in flight at its lower end where an ideal solid rock foundation is available, and it has a guard lock at its upper end to protect the long 13 mile reach from high water levels on lake St. Francis. The improvement shown is similar to that laid out and recommended in the Report of 1921. It will be referred to as the Hungry Bay-Melocheville project, and is shown on plates 58 and 59.

230. A waterway built along this route does not require the removal of a very large amount of excavation as the ground surface is uniformly below the level of lake St. Francis and yet the retaining embankment will not be high, and no creeks or rivers are crossed at any point in the route. In this project very little solid rock has to be removed. Three combined railway and highway crossings and three crossings for highway traffic are provided in this section. The length of restricted navigation in the canal is about 13 miles, exclusive of locks.

231. The project is designed to have ultimately double flight locks at Melocheville, these together overcome a lift of 80 feet and give a traffic capacity of 40,000,000 tons per year.

232. As the traffic capacity of one set of flight locks is about 16,000,000 tons per year, it is thought the construction of the second set may be delayed for some years and the project is laid out in that way. In order, however, to facilitate the later construction of duplicate locks, estimates and plans provide for the execution of the foundations and the construction of walls to the ordinary level of lake St. Louis.

233. The estimated cost of the Hungry Bay-Melocheville project for navigation alone is $37,541,000 of which an expenditure of $3,901,000 can be delayed until the completion of duplicate locks as described above. For detailed estimates see tables Nos. 14 and 15. The above estimate provides for the use of lift bridges of 200 feet clear span.

234. An overland canal of similar design can be built on the north shore of the river. See plates 60 and 61. It would be slightly shorter and crossed by fewer bridges, but it would be more costly as three rivers are crossed and good foundations for locks are deeper. Its cost is estimated at $40,378,000 as shown in tables Nos. 16 and 17.

235. The length of restricted navigation in the above scheme can be reduced by the construction of a lock and dam system of river improvement. This obviously involves power potentialities and the substructure of a power-house should be incorporated with the dam required in such an improvement. If this be done it would become the first stage of the project recommended.

236. An advantage of this north canal is that it could be combined with a river improvement, subsequently made for power, by constructing two short connections to the river. The length of restricted navigation would thus be reduced. See paragraph 174*b* of the Main Report. The estimated cost of these two connections is $1,922,000. See table No. 17.

Improvement of Soulanges Section for Power Alone

237. Various projects for improving the Soulanges section for power alone were investigated. In general, the same problems presented themselves as in improvement for both navigation and power. It was found that no economical project could be laid down which would not interfere with present 14-foot navigation in the Soulanges canal, and also no project could be laid down which would not interfere, in some stage of its development, with the present Cedars plant. Analysis shows that the best form of improvement is the Ile aux Vaches Three-Stage scheme with 14-foot side canals taking the place of the deep waterway shown in the recommended project. The cost of this project is estimated at $180,711,000, as shown in tables Nos. 23 and 24.

238. Overland canal projects which carried a diversion for power all the way from the foot of lake St. Francis by the St. Louis and Chateauguay rivers to the St. Lawrence river at the head of La Prairie basin have been considered. Two methods of utilizing a diversion made in this way were investigated. One was by a single-stage scheme and the other by a double-stage scheme, placing one drop at the junction with the Chateauguay river and the other at the head of La Prairie basin. These projects appeared to the best advantage when the diversion made did not exceed 30,000 cubic feet per second, but even then were not economical when compared with improvements of the Soulanges and Lachine sections by means of other projects described.

LACHINE SECTION

239. Description. This section may be taken as extending from deep water at the head of lake St. Louis to the Alexander pier in Montreal harbour, mile 159 to mile 183. It is 24 miles long and covers the same territory as Division No. 1 in the Report of 1921. The section includes the expansion of lake St. Louis, the narrow stretch of river between Caughnawaga and Heron island with Lachine rapids at its foot, the short expansion of La Prairie basin and the swift water between Nuns island and Montreal. The total fall in the section with 242,000 c.f.s. flowing past Lachine is 48 feet. This is distributed as follows: Between Melocheville and the outlet of the Chateauguay river, the fall is three-tenths of one foot. Between the Chateauguay river and Lachine wharf, the fall is 1·1 feet. Between Lachine wharf and the head of Lachine rapids, the fall is 7·8 feet. Between a point half a mile above the head of Ile au Diable and the foot of Heron island, which may be taken as Lachine rapids, the drop is 23·5 feet. Between the foot of Lachine rapids and Victoria bridge the fall is 6·8 feet, and between Victoria bridge and Montreal harbour the fall is 9·0 feet.

240. Upstream navigation through the Lachine rapids is impossible and the only boats that navigate them on the downstream journey are the specially built passenger boats which operate for the tourist trade. All freight boats use the present Lachine canal which provides a 14-foot draft. This canal extends from Lachine to Montreal, a distance of 8½ miles, and has five locks.

241. Several urban centres are located along the river in the Lachine Section. The city of Lachine and the towns of St. Annes, Pointe Claire, Dorval,

Beauharnois and Caughnawaga are located on the shores of lake St. Louis. The city of Verdun and the town of La Prairie are located on the shores of La Prairie basin. The city of Montreal extends along the north shore of the river from La Prairie basin to the wide and spacious river below St. Helen's island. The town of St. Lambert is located on the south shore at the end of Victoria Bridge.

242. The lands on the north side of Lake St. Louis for eight miles above Lachine are low, specially near the lake shore. In this strip of land and at the Chateauguay Basin on the south side a large investment has been made in summer homes which would be inundated should the lake surface be raised materially above its high water levels. Considerable areas east of La Prairie are often inundated when the river is breaking up in April. The low parts of the city of Verdun are dyked to protect them from inundation during the high water levels of the breakup period.

243. The Ottawa River flows into the St. Lawrence through four outlets two of which, Vaudreuil and St. Anne, flow into Lake St. Louis; and two, the Mille Isles and Des Prairies Rivers, join the St. Lawrence at the foot of Montreal Island about fifteen miles below Montreal Harbour. The percentage of flow through each of these channels varies with the stage of lake of Two Mountains.

244. The maximum recorded flood occurred on May 17, 1876, when 195,000 c.f.s. flowed into lake St. Louis from the Ottawa river, and 550,000 c.f.s. flowed out of lake St. Louis to La Prairie basin. In three other years records of 160,000 c.f.s. in the St. Anne and Vaudreuil channels and 500,000 c.f.s. at the outlet of lake St. Louis are recorded. Records show that extreme flood levels on lake St. Louis occur between the 29th of April and the 29th of May.

245. Lake St. Louis is a relatively deep and short lake which overlies a trough in the rock surface. This trough provides a deep straight uniform channel from Melocheville to the mouth of the Chateauguay river. From this point east to the Canadian Pacific Railway bridge below Lachine, the bed is irregular and is obstructed by dykes of igneous rock which penetrate the surface and make navigation dangerous for any kind of craft. Between the Canadian Pacific Railway bridge and the head of the Lachine Rapids, a short stretch of uniform, rock floored river intervenes. From the middle of this section, the city of Montreal draws its water supply by use of a submerged pipe and intake crib. From the head of Lachine Rapids to their foot, the river gradually expands in width and igneous dykes penetrate the surface in many places, especially on the north side. Through the Lachine rapids, downstream navigation is only possible along one central channel and this is flanked by rocky projecting dykes which break up the water into innumerable cascades or abrupt falls.

246. In winter the regimen of the St. Lawrence river between the head of lake St. Louis and Montreal harbour undergoes a great change. With the advent of cold weather the water flowing out of lake Ontario gradually cools as it proceeds to the sea. The rate of this cooling is proportional to the surface area exposed and lake St. Francis, lake St. Louis and lake St. Peter are effective agents in lowering the temperature of the water. The water flowing through the lakes of the Ottawa is cooled in the same way but more rapidly than that of the St. Lawrence. Usually, about the 1st of December the water flowing into Lake St. Louis from the Ottawa will be found to be at about the freezing point and lake of Two Mountains will then be freezing over. About two weeks after lake of Two Mountains is cooled down to 32 degrees Fahrenheit, lake St. Peter, 65 miles below Montreal, reaches the freezing point and, if the weather is cold, an ice bridge immediately forms at that point. At this time, the temperature of the river at Kingston will be found to be about 6 degrees above the freezing point,

and that of the water in lake St. Louis and lake St. Francis some degrees above that of lake St. Peter and below that at Kingston. If cold weather continues, lake St. Louis and lake St. Francis soon reach the freezing point and cover with ice. Usually, about 16 days after an ice cover forms on lake St. Peter, the water at the outlet of lake Ontario, opposite Kingston, is cooled down near to the freezing point and ice forms. Should warm weather intervene shortly after lake St. Peter, lake St. Louis or lake St. Francis freeze over, they may open up again, especially if winter is ushered in by a short period of very cold weather in which an ice cover is formed on these lakes, while lake Ontario is still relatively warm.

247. The ordinary flow out of lake St. Louis varies from 210,000 to 260,000 cfs. in the early part of winter. The maximum cross-sectional area of lake St. Louis, opposite Beauharnois, is about 490,000 square feet at low water. Opposite the foot of ile Perrot and opposite the mouth of the Chauteauguay river, the area is reduced to about 150,000 square feet. As will be observed from the size of the above cross-sections, the velocity of the water moving through the upper ten miles of lake St. Louis is less than 1.7 feet per second and, as may be expected, its surface area west of the mouth of the Chateauguay, 48 square miles, freezes over almost as soon as it is cooled to the freezing point at the beginning of each winter. Between the mouth of the Chateauguay river and the Lachine Wharf, the cross-sectional area of the river is about 116,000 square feet and the average velocity of the moving water in winter is over two feet per second. In this stretch of river no ice cover forms except in the shallow bays near shore. Between Lachine wharf and the head of Lachine Rapids, the sectional area is about 53,000 square feet and velocities are so high that no ice cover forms except on a narrow fringe along the shore.

248. The surface area of water ordinarily exposed in winter between ice cover in lake St. Louis and the head of La Prairie Basin is about 11 square miles and the volume of ice formed by this exposure is usually about 170,000,000 cubic yards. This ice is carried through Lachine rapids and is largely stowed in the form of hanging dams under the ice cover which forms below and in La Prairie basin. More than half of the exposed surface mentioned above is upstream from the entrance to the Lachine canal where the velocity of the water is almost low enough to form an ice cover.

249. At the foot of Lachine rapids, the river spreads out into the shallow La Prairie basin, through which the water moves slowly for about one mile. Below this stretch of quiet water, a number of boulder ridges rise out of the water. These separate the river into three or four more or less distinct channels through which the water moves quite rapidly to the foot of the basin and on past Victoria bridge to Montreal harbour.

250. In the early stage of winter the southerly and northerly parts of La Prairie basin cover with ice, but a central channel near Nuns island remains open until the ice pack which starts in lake St. Peter makes upstream past Montreal, under Victoria bridge, and into the basin. While the pack below Montreal is building upstream, the water level at Montreal gradually rises until the head of the pack passes that point. After that, it falls slightly and remains at a constant level until the breakup period brings down large quantities of frazil and slush and raises the water level again. The maximum January rise in Montreal harbour is ordinarily about 16 feet. With continued cold weather the water level at the head of the La Prairie basin continues to rise slowly as more and more ice is brought to it from above. In general, the highest level recorded is coincident with the last week of cold weather in February or March. Usually at that time the water level is about 11 feet above ordinary summer levels. Under these conditions, the surface slope in the ice gorged section between Lachine rapids and Montreal is about 1.6 feet per mile.

251. In April, warm rains and sun weaken the surface ice which holds the hanging dams in place and a large quantity of surface ice, frazil and slush moves from its wide berth in La Prarie basin to the narrow restricted river below Victoria bridge. This movement increases the length of the gorged section at Montreal. Under these conditions, the total surface drop becomes much greater than in the depth of winter and high water levels, 16 feet above summer stage for similar discharges are frequently found opposite the city of Verdun and in La Prairie basin generally.

252. It is believed that the operation of ice breakers below Montreal in recent years has reduced the height to which such flood levels rise. This is due to the fact that the length of ice cover in the river below the gorged section is reduced before it begins to move and a jam far down the river where it is very narrow is prevented by clearing lake St. Peter of ice at an early date in April. It is clear, however, that the length of gorged section near the City of Montreal is not affected by the ice breakers operations.

253. The St. Lawrence river flows over a floor formed chiefly of solid rock from about a mile above Lachine to below Montreal harbour. Rock surface is exposed above the water level of the river at Lachine and Caughnawaga. It is exposed on both shores throughout the length of Lachine rapids and at many points in La Prairie basin and below Victoria bridge in the harbour of Montreal. Test borings also show the solid rock surface to be close to the river bed on the north and west sides of La Prairie basin. North and east of the river, between Lachine and Verdun, the solid rock surface is above the bed of the river, but between Verdun and Montreal harbour it is below.

254. Plans for Improvement. The Board has considered the following plans for the improvement of the Lachine section:—

(1) A side canal with locks for navigation with control of lake St. Louis.

(2) An all river improvement for both navigation and power.

(3) A side canal with lock for navigation without control of lake St. Louis.

255. Plan Recommended for Project. The plan recommended by this Board is for a side canal with locks for navigation with control of lake St. Louis and is described in paragraphs 183 to 185 of the Main Report. It is shown on plates Nos. 62 to 64. Its estimated cost is $53,000,000. Detailed estimates are given on tables Nos. 30 and 31.

256. The works comprised in this improvement may be listed as follows:—

(*a*) A long submarine channel extending from deep water in lake St. Louis to Lachine; this channel to be 600 feet wide for 4 miles of its length and 300 feet wide for 1.2 miles of its length.

(*b*) An overland canal extending from Lachine to a junction with deep water opposite the Alexandria pier in Montreal harbour.
This canal flanks the north shore of the river and is about 10 miles long. It is to be equipped with a pair of guard gates and supply weir situated 3.4 miles east of Lachine and with three lift locks. One lock is at Verdun, 5 miles east of Lachine; one is at the foot of Nuns island; and one is at the entrance of Montreal harbour, north of Victoria bridge.

(*c*) A dam across the St. Lawrence river at ile au Diable together with dams at the two northern outlets of Lake of Two Mountains and such other works as are required to hold the low water level of lake St. Louis to elevation 71.

257. As currents at the outlet of lake St. Louis cross the submarine channel at a small angle with its axis, the navigation channel is given a width of 600 feet between deep water in lake St. Louis and the end of the present Lachine

Canal breakwater. Along the inside of this breakwater the channel has a width of 300 feet. Between Dorval island and the north shore, an enbankment is provided for reduction of cross currents at this point.

258. The overland canal above described runs parallel with the river and near the north shore to a point 7,800 feet east of the present canal embankment at Lachine. It is to be separated from the river for this length by timber cribwork. This makes it possible for the excavation inside this embankment to be done in the dry. A double track vertical lift bridge is provided at the intersection of the Canadian Pacific Railway with the proposed canal at Highlands. The proposed canal leaves the shore of the river 7,800 feet east of Lachine and proceeds for a length of about one half mile in a prism 55 feet deep which is excavated in earth. East of that point it is carried in earth and rock for a length of about three miles through low flat country to the shore of the river opposite the Verdun Asylum, where a lock with a lift of 20 feet is located.

259. Retaining embankments are placed on both sides of the canal for a length of three miles above the lock at Verdun, the south embankment being connected with the north end of the dam at ile au Diable. Syphon culverts are located at the head of the Montreal aqueduct. A subway for highway traffic is provided under the canal and is located between the guard gates and the Verdun lock; it provides for two openings 25 feet wide and 15 feet high.

260. East of the Verdun lock, the canal is carried for a length of 2½ miles in a high level basin formed by the north shore of the river on one side and an embankment on the other. In this reach the prism, 300 feet wide, is in shallow excavation. At the lower end of this basin the Nuns island lock, with a 12-foot lift, is located at the foot of the island near the north shore. Water is to be supplied to this basin by a supply weir at the Verdun lock and is discharged from it by a weir in an embankment north of the lock at Nuns island.

261. Between Nuns island lock and Victoria bridge the canal is formed in deep rock excavation in a basin which is separated from the river by a long embankment high enough to protect the reach from flood levels in the river. At Victoria bridge a weir and culvert are provided for discharging the surplus water of the canal and the local drainage into Montreal harbour. Two lift bridges are provided for the railway and highway traffic at the Montreal end of Victoria bridge.

262. About 1,500 feet below Victoria bridge the Montreal lock, with a maximum lift of 21 feet, carries navigation into Montreal harbour. Retaining walls and the upper entrance piers of the lock hold the reach level.

263. In the project recommended, a dam is located at île au Diable. This structure is of the open wicket type and is introduced to reduce the volume of excavation required in the channel which leads from deep water in lake St. Louis to the lock at Verdun. It will also reduce the velocities at the outlet of lake St. Louis and will also reduce the cost of power development when such development is undertaken. The dam proposed is to consist of large concrete piers, 160 feet centre to centre, with steel truss bridges and drop wickets for lowering in the spring of each year after the flood flows are passed. These wickets are to be opened at the end of each navigation season. The throttling effect of the piers during flood discharge is to be compensated for by means of a small diversion channel which leads from the navigation channel at the north end of the dam. It is designed to raise the low water level of lake St. Louis to elevation 71.0.

264. As this is higher than the extreme low water of Lake of Two Mountains, this rise in level will reflect on the level of that lake, and dams will be required at its two northerly outlets in order to control the distribution of outflow.

265. If flood flows in the future were to be no greater than in the past, the works described above would be all that are required to bring about the improvement. However, other complications enter. The immediate improvement of the International Section and the future improvement of the Lachine Section, place certain restrictions on maximum winter outflows. Then again power values make it desirable that winter flows be made more regular than they are in nature. Moreover, navigation interests demand some regulation of this flow. The scheme of regulation of lake Ontario submitted with the Board's report, endeavours to secure the greatest good to the greatest number of interests possible, but in doing so, it contemplates increasing the flood flows in May to the extent of about 15,000 cfs. in extreme years. The conservation works on the Ottawa, which have been recently built and others which are in progress of construction, will compensate for the proposed increase in flow out of Lake Ontario at these periods.

266. Alternative Plans. Before selecting the side canal project with the control of lake St. Louis above described, the Board carefully considered the practicability of utilizing the river channel for navigation by means of the construction of locks and dams with channel excavation. An apparently practical place for a dam and lock improvement is suggested by the nature of the river bed and the drop in water level at Lachine Rapids. Another place is suggested by the drop in water level below Victoria bridge. A dam and lock at either site might be combined with a dam and lock at the other, or either might be combined with a side canal and a number of locks above or below it. In investigating conditions, it was found that the stretch of river between Lachine wharf and Lachine rapids cannot be made safe for deep draft navigation without an enormous amount of channel enlargement, a large part of which must be secured by the excavation of solid rock.

267. To maintain the standards on which the waterway is designed, maximum velocities in the navigable channels must be kept down to 5 feet per second, and a cross-sectional area of 100,000 square feet must here be provided to care for a discharge of 500,000 cfs., which is sometimes reached in the month of May. This requires a net enlargement of at least 35,000 square feet for a length of 5½ miles, or the excavation of about 37,000,000 cubic yards, the greater part of which is solid rock.

268. Obviously, no project involving such an amount of excavation can be justified as an improvement for navigation when the side canal, as described, can be built for one-third of the cost of a river enlargement between Lachine Wharf and the head of Lachine rapids.

269. If the enlargement of the river between Lachine Wharf and Lachine Rapids were carried to the point where an ice cover would be secured, the amount of excavation required would be much increased.

270. Further, conditions in this reach are especially hard to deal with because the natural depth in part of the river is 35 feet while in another part it is only 10 feet. This means a very high velocity in some parts and a very low velocity in others.

271. It is not possible to execute a project for permanently raising the level of La Prairie Basin by means of a dam at Victoria Bridge without securing an ice cover in the river above Lachine Rapids because the 170,000,000 cubic

yards of ice must be stowed in La Prairie Basin if the river remains open above it and because a twelve-foot drop across La Prairie Basin must be available to overcome resistances in a gorged condition.

272. Even though the enlargement of the river above Lachine Rapids should be justifiable as a power venture and such enlargement should cut off the movement of ice from above, the building of a dam and lock at Victoria Bridge can not be justified as a navigation proposition, as comparative estimates show that it is cheaper to raise a section along the north shore of the basin than it is to raise the whole of the basin itself. This is due to the great length of dykes and other works which are necessary to protect the town of La Prairie and the low land adjacent from the raised level in the basin, as well as to the length of the dam itself.

273. From a power point of view, it might be suggested that the level of Lake St. Louis could be extended through Lachine Rapids and La Prairie Basin to a dam, power house and lock at Victoria Bridge where the whole head in the section would be concentrated at one point. Such a scheme would involve long and high dykes on either side of La Prairie Basin as well as extensive pumping and drainage works. As the water level in the river below Montreal would still rise a considerable amount due to ice resistance in winter, nothing very material would be gained from the large expenditures required to build the high dam and dykes above mentioned.

274. Preliminary estimates of the cost of the above project and the value of the extra power derived by such a scheme made it evident at once that the levels of lake St. Louis should be extended only to the head of La Prairie basin.

275. A dam at Victoria bridge with a power plant at that point combined with a dam and power house at the foot of Lachine rapids is not a workable proposition as the total head available, especially in winter, is too small to divide. Then again, if a power plant were located at Victoria bridge it would always be in danger of losing a part of its head through a future rise in tail-water level by a dam in the main river below Montreal.

276. The power problems, therefore, centre upon how power plants might be built near the foot of Lachine rapids and how water might be conducted to them with a minimum loss of head. This can be done, so far as summer conditions are concerned, by a moderate enlargement of the cross-sectional area of the river between the foot of lake St. Louis and the head of La Prairie basin, such as is shown by the Lachine Rapids project in the Report of 1921.

277. The Lachine Rapids project, as described in that Report, contemplates the enlargement of the river so that it will give a cross-sectional area of 83,000 square feet when lake St. Louis stands at elevation 71 at the upper entrance of the Lachine canal. Analysis of such enlargement shows that it would care for the maximum flood flows occurring in the St. Lawrence at this point in summer, namely 550,000 cubic feet per second, without raising the level of lake St. Louis above the elevation to which it has gone in nature and still leave a reasonable head for the development of power at the head of La Prairie basin. In winter, however, this relatively small sectional area would make it imperative that open water be continuously maintained between the power plant at the head of La Prairie basin and lake St. Louis in order to insure the quiet passage of expected flows without excessive damage to properties around lake St. Louis.

278. It is thought that this improvement cannot be operated so as always to maintain open water immediately above the power dam and power plant at the head of La Prairie basin, as there is danger of ice accumulating above the piers of the dams and power houses and making upstream so fast that an ice

jam would be formed before anything could be done to release it. If such an ice jam should form, the velocity at its head would be about 3.2 feet per second with a discharge of 265,000 cfs., which records show must be passed under certain winter conditions. As shown in appendix " E," this velocity is too high to insure the maintenance of a free and open channel underneath this ice cover and any filling up or gorging of this free and open channel between the power house shown at the head of La Prairie basin and the outlet of lake St. Louis opposite the entrance to the Lachine canal will cause a great rise in water level in lake St. Louis and damage to the property around its shores.

279. As a consequence of this situation, the Board finds that the Lachine Rapids project, as in the Report of 1921, requires modification. An enlargement of the section of the river from the foot of lake St. Louis to the power plants at the head of La Prairie basin so that it would provide a cross-sectional area of about 115,000 square feet or a velocity of $2\frac{1}{4}$ feet per second under extreme winter flood conditions would, no doubt, provide a safe and workable scheme for the development of this section of the river. This would involve an enlargement of the river to the extent of about 50,000 square feet for a length of about 6 miles, requiring the removal of about 50,000,000 cubic yards, almost all of which is rock. Such a project would be enormously costly and would be justified as a power development, only if no chaper method of improvement were available.

280. Power Development. The navigation improvement selected by this board and set forth in paragraphs 183 to 185 of the Main Report can be associated with a subsequent power improvement (paragraph 186, Main Report), which provides for a diversion of a large portion of the flow of the river, through an artificial channel which makes it possible to use the natural capacity of the river in an ice-covered condition from the outlet of lake St. Louis to the head of La Prairie basin. The artificial channel is designed to carry a large amount of water with a small area of exposure. This complete power project is intended to be constructed in two successive stages, the first of which would be completed and put into operation before the second stage is undertaken. In this way the cost of the project, including interest, would be much less than if it had all to be built and completed at one time. It is shown on plates Nos. 65 and 66. Its estimated cost when built subsequent to the improvements described for navigation is $123,213,000. Detailed estimates are shown on tables Nos. 32 to 34.

281. The works in the first stage of the power project may be summarized as follows:—

(*a*) A power house on the south shore east of Paquette island. This power house is to be equipped with 19 units of 22,900 horsepower each and is designed to develop 391,000 horsepower at a $31\frac{1}{2}$-foot head.

(*b*) A canal extending from the foot of lake St. Louis west of the village of Caughnawaga to the power house. The power canal is to be 1,000 feet wide on the bottom and 26 feet deep in the submarine section west of Caughnawaga, and 300 feet wide on the bottom and 40 feet deep in the overland section, east of that point. It is to be protected at the upper end by gates and lined with concrete through the solid rock section between Caughnawaga and the power house forebay.

(*c*) A reconstruction of the dam, described in paragraph 263, so that it can retain and hold up the level of lake St. Louis to elevation 71 during winter conditions.

282. The works in the second stage of the power project may be summarized as follows:—

(*a*) A power house equipped with 19 units of 25,700 horse-power each, situated at the foot of the Lachine rapids extending into the river north of Paquette island. This power house is designed to develop 422,000 horse-power at 33⅓ foot head.

(*b*) A dam extending from the north end of this power house to Heron island, thence along the axis of Heron island to its head, thence upstream along the rock outcrops of the river to a junction with the dam previously described in stage No. 1 about 1,500 feet south of its intersection with the north shore of the St. Lawrence river.

(*c*) The removal of about 3,500 feet of the south portion of the dam as modified for the first stage, leaving only such part of this section as may be used for bridge piers.

283. Under this system of improvement, the natural river channel having a cross-sectional area of about 70,000 square feet would carry about 145,000 cfs. at a velocity of about 2¼ f.s. and the artificial channel having an area of 12,800 sq. ft. would carry 120,000 cfs. at a velocity of about 9.4 feet per second. Both of these channels together would carry about 265,000 cfs. with an overall fall of about 3½ feet. This system of improvement contemplates an ice cover throughout the entire section above the power plants exclusive of the area exposed in the artificial channel. It is a much more economical system of development than a direct enlargement of the river. In order to prevent sudden changes in the level of Montreal harbour, close supervision would be required of opening and closing gates as power is thrown on and off the plants.

284. The estimated first cost of completing the first stage of this project after the control dam for navigation is built is $81,247,000. When interest during construction and interest during marketing period determined by an annual growth in the use of power of 75,000 horse-power is added, its cost becomes $100,227,000. The estimated first cost of completing the second stage of this project is $41,966,000 and when interest during construction and interest during marketing period is added its total ultimate cost becomes $46,336,000. See table No. 34.

285. It will be noted that the ultimate cost of obtaining power from this section of the river is $180 per horse-power while the cost of obtaining power from the Soulanges section is $125 per horse-power. As power developed in the Lachine section is about 18 miles nearer Montreal than power in the Soulanges section, it would probably justify an additional capital expenditure. Estimates indicate, however, that power in the Soulanges section can be developed and delivered to Montreal for less than power in the Lachine section. It is, therefore, but reasonable to expect that power development in the Soulanges section will precede that in the Lachine section, and no immediate development for power in the latter need be provided for in the project adopted to give through navigation, but provision should be made for development in the future in the most economical way.

286. *Alternative Plans for Side Canal.* Having established that the best form of improvement for this section is by an overland canal with subsequent improvement of the river for power, the reasons for the route adopted by the Board will now be discussed.

287. The Report of 1921 recommends improving the Lachine section by means of an overland canal extending from Lachine to Verdun, together with a series of raised basins, thence to Montreal harbour.

288. From a construction point of view the location of 1921 had many desirable features, but in view of the fact that the city of Verdun is growing fast and towards the west, it is thought to be unwise to build the waterway so far inland, because some day the lands west of the canal in this location would, undoubtedly, be extensively developed and the population therein would demand either tunnels, which will be very costly, or draw bridges which will be impossible to operate without interference with navigation and without annoyance to the public.

289. An overland navigation canal between lake St. Louis and the river below Montreal, if built on the south shore would be much longer than on the north shore. It would have to care for the drainage of a number of streams which flow into La Prairie Basin from the south. If a navigation canal were built on the south side, the power canal would have to be built on the north shore. Estimates show that the cheapest combination is navigation on the north side and power on the south side.

290. An overland project can be built quite well with lake St. Louis allowed to fluctuate as at present and if built in that way will not interfere with the future development of power. It is believed, however, that in the general interests of a future improvement of the river for power a control dam for summer use should be incorporated into the project. This will establish an open water control of the level of lake St. Louis, thereby saving 5 feet of excavation in the long submarine channel leading from deep water in lake St. Louis to Lachine and in the long overland canal extending from Lachine to the first lock at Verdun. This will not effect a saving sufficient to cover completely the cost of building a bridge and dam at the head of ile au Diable but on account of the improvement to navigation brought about by this raise in level of lake St. Louis generally and, on account of the future benefits which such a control would confer on power development, the Board believes that the improvement of the river for navigation should be made in this way.

291. The cost of improving the river for navigation without establishing a control of lake St. Louis is $50,848,000, as shown in table No. 35. This compares with $53,000,000, as shown in table No. 30, for the project with control.

292. In the project recommended, the drainage of the St. Pierre river and the outflow from the Montreal Water Works Pumping Station are discharged into the basin between Nuns island and the Montreal lock. From this basin it is to be discharged through two arch culverts under the approach to the Victoria bridge into Montreal harbour. In this way the water level in the basin above Victoria bridge and at the outlet of the St. Pierre river will be kept many feet lower in winter than the level of La Prairie basin opposite. In summer, however, it will be somewhat higher than it has been in nature but it will not be higher than extreme levels of La Prairie basin in May.

293. The estimated cost of this scheme is greater than a number of other projects which the Board has considered but it interferes less with vested interests than any other project that has been developed. According to the Board's standards, its estimated cost is about the same as that of the project recommended in the report of 1921.

294. As mentioned earlier in this report, the City of Montreal draws its domestic water supply from the St. Lawrence river about 1¼ miles above the head of Lachine rapids. Ordinarily, an aqueduct of quite small proportions is large enough to carry all the water required by a large city. In this case, however, the aqueduct is a large canal; its cross-sectional area is about 2,500 square feet for a length of about 4 miles and 1,500 square feet for a length of about 1 mile. It was enlarged to its present size with the idea of using it for power as

well as for a domestic water supply. The work connected with this power project has been halted for some years. The carrying capacity of the parts of the enlargement which have been completed is about 5,000 cfs. In the plan recommended, provision is made for passing 5,000 cfs. into this canal at its head and also for passing 5,300 cfs. from the basin above Victoria bridge to Montreal harbour. In this way, the recommended project is designed to permit the City of Montreal to complete their aqueduct project as originally planned.

295. The project recommended in the Report of 1921 contemplated permitting the potentialities of the power project to be realized but, in that case, a change in the location of the power-house was required and only the westerly half of the aqueduct could be used for power.

296. A scheme for utilizing 1.6 miles of the prism of the present aqueduct for the navigation canal and developing a large terminal basin for future shipping north of Nuns island was drawn up and carefully considered. West of the C.P.R. bridge at Lachine this project is the same as the recommended project. Eastward 1,500 feet from the C.P.R. bridge the waterway in this scheme turns inland 50 degrees on a curve of one mile radius, then follows along the axis of the present aqueduct for 8,500 feet, then turns 24 degrees toward the river and passes west of the Verdun asylum. At this point, a lock which overcomes a difference in level of 20 feet is placed. Eastward from this lock the waterway proceeds in an artificial basin, as in the plan recommended, about 16 feet above the level of La Prairie basin. The lock is placed, however, at the foot of Nuns Island, but the raised basin is continued to below Victoria bridge where a lock which overcomes a maximum difference of level of 33 feet is placed. The project requires large and expensive draïnage works as the outflow of the St. Pierre river and that of the sewers of Verdun have to be carried to Montreal harbour below Victoria bridge. It also involves building a special water supply conduit from a point in the river opposite the old entrance of the Montreal aqueduct to join the present aqueduct east of the point where the waterway leaves it. This artificial basin, as shown, is 3.6 miles long and is flanked by a retaining embankment of earth and rock on one side and the Verdun dyke on the other. It would afford opportunities for the development of the rock facilities in the City of Montreal.

297. The estimated cost of the project is $1,500,000 less than the project recommended. It would, however, require co-operation from a great many divergent interests; it would require the City of Montreal to abandon the development of power from its enlarged aqueduct, and it might affect living conditions in the City of Verdun by permanently raising the ground water level to an uncomfortable extent. Its alignment is not as good as in the project recommended and the obstructed view at the turn above the upper end of the aqueduct would increase the hazard of collision. For these reasons it is not recommended.

POWER HOUSE INSTALLATIONS

298. The installed capacities of the power houses in the various projects considered are shown on tables 36 to 38.

TABLE I.—ESTIMATE OF COST INTERNATIONAL RAPIDS SECTION—SINGLE-STAGE SCHEME (242)—*Continued*

(As proposed by United States Section)

Item	Quantity	Unit	Unit price	Amount	Sub-totals
1. Dam and power houses at foot of Barnhart Island—			$ cts.	$	$
(a) Dam, except unwatering—					
Excavation, earth	615,000	Cu. yd.	0 80	492,000	
Excavation, rock, dry	163,000	"	2 25	367,000	
Concrete	1,131,000	"	12 00	13,572,000	
Foundation contingencies	....	10%	....	1,357,000	
Gates	46	Each	7,500 00	345,000	
Towers, track, and bridge	46	"	6,300 00	290,000	
Operating cranes	3	"	16,000 00	48,000	
Stop logs	6	Sets	10,000 00	60,000	
					16,531,000
(b) Power-house substructures—					
United States power house—					
Excavation, earth	1,076,000	Cu. yd.	0 75	807,000	
Excavation, rock	56,000	"	2 25	126,000	
Concrete, below draft-tube floor	138,600	"	10 00	1,386,000	
Concrete, above draft-tube floor	701,800	"	15 00	10,527,000	
Canadian power house—					
Excavation, earth	702,000	"	0 75	527,000	
Excavation, rock	104,000	"	2 25	234,000	
Concrete, below draft-tube floor	21,300	"	10 00	213,000	
Concrete, above draft-tube floor	678,700	"	15 00	10,180,000	
					24,000,000
(c) Unwatering dam and power houses—					
General excavation, earth, dry	614,000	Cu. yd.	0 80	491,000	
General excavation, dredging	1,450,000	"	1 25	1,813,900	
Cofferdams and pumping	....	....	....	10,745,000	
					13,049,000
(d) Abutments to power houses—					
United States power house—					
Excavation, earth	295,000	Cu.yd.	0 65	192,000	
Excavation, rock	2,900	"	3 50	10,000	
Backfill	200,000	"	0 40	80,000	
Concrete	96,400	"	12 00	1,157,000	
Canadian power house—					
Excavation, earth	75,500	"	0 65	49,000	
Excavation, rock	2,000	"	3 50	7,000	
Backfill	30,000	"	0 40	12,000	
Concrete	46,500	"	12 00	558,000	
					2,065,000
(e) Tail-race excavation—					
United States powerhouse—					
Dredging	1,549,000	Cu. yd.	1 25	1,936,000	
Canadian power house—					
Excavation, earth	630,000	"	0 75	473,000	
Excavation, rock	158,000	"	1 75	277,000	
Dredging	890,000	"	1 25	1,113,000	
					3,799,000
(f) Rail connections to power houses—					
Railroad to United States power house—					
Track	0·8	Mile	40,000	32,000	
Railroad to Canadian power house—					
Track	1·7	"	40,000	68,000	
Bridges	....	....	....	139,000	
					239,000
(g) Superstructures and machinery—					
United States power house—					
Superstructure, gates, racks, cranes	....	....	....	6,000,000	
Generators and turbines	136,500	c.f.s.	109 20	14,906,000	
Switching	1,663,000	H.P.	3 70	4,303,000	
Canadian Power house—					
Superstructure, gates, racks, cranes	....	....	....	6,000,000	
Generators and turbines	136,500	c.f.s.	132 30	18,059,000	
Switching	1,663,000	H.P.	3 70	4,303,000	
					53,571,000
					113,254,000

TABLE I.—ESTIMATE OF COST INTERNATIONAL RAPIDS SECTION—SINGLE-STAGE SCHEME (242)—*Continued*)

(As proposed by United States Section)

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
2. Navigation works (channels 25 feet deep)—					
(a) Approach channel above Robinson Bay lock —					
Excavation	1,339,000	Cu. yd.	0 65	871,000	
					871,000
(b) Robinson Bay lock (No. 8)—					
Excavation, open, earth	125,000	Cu. yd.	0 65	81,000	
Excavation, trench, earth	274,000	"	5 00	1,370,000	
Backfill	575,000	"	0 40	230,000	
Concrete	429,800	"	10 00	4,298,000	
Gates	6	Pairs	....	785,000	
Operating machinery	....	....	....	310,000	
Emergency dam	....	....	....	175,000	
Approach walls—					
Rockfill	40,000	Cu. yd.	2 00	80,000	
Timber cribs	72,300	"	8 00	578,000	
Concrete	18,470	"	10 00	185,000	
Piling	37,800	Lin. ft.	0 85	32,000	
Office and dwellings	....	....	....	40,000	
					8,164,000
(c) Canal Prism, Robinson Bay lock to Grass River Lock—					
Excavation, earth	1,057,000	Cu. yd.	0 65	687,000	
					687,000
(d) Grass River Lock (No. 7)—					
Excavation, earth	904,000	Cu. yd.	0 75	678,000	
Excavation, rock	13,200	"	3 50	46,000	
Backfill	576,000	"	0 40	230,000	
Concrete	332,100	"	10 00	3,321,000	
Gates	6	Pairs	....	730,000	
Operating machinery	....	....	....	300,000	
Approach walls—					
Timber cribs	41,200	Cu. yd.	8 00	330,000	
Piling	71,200	Lin. ft.	0 85	61,000	
Concrete	27,000	Cu. yd.	10 00	270,000	
Office and dwellings	....	....	....	40,000	
					6,006,000
(e) Approach channel, Grass River Lock to river—					
Excavation, earth	364,000	Cu. yd.	0 65	227,000	
					227,000
(f) Dike at Grass River Lock—					
Fill, earth	368,000	Cu. yd.	0 75	276,000	
Riprap slope protection	10,300	"	3 00	31,000	
					307,000
(g) Waste weir at Grass River lock—					
Excavation, earth, open	133,400	Cu. yd.	0 65	87,000	
Excavation, earth, trench	16,200	"	5 00	81,000	
Backfill	46,000	"	0 40	18,000	
Piling	60,000	Lin. ft.	0 85	51,000	
Concrete, mass	25,900	Cu. yd.	12 00	311,000	
Concrete, paving	10,000	"	15 00	161,000	
Gates and operating machinery	8	Sets	....	48,000	
					757,000
(h) Drainage ditch north of Grass River lock—					
Excavation	3,000	Cu. yd.	0 65	2,000	
					2,000
(i) Diversion dike and flood channel at mouth of Grass River—					
Dike, rockfill	63,000	Cu. yd.	2 00	126,000	
Dredging, earth	227,000	"	0 80	182,000	
					308,000
(j) Diversion, Ottawa Branch, New York Central Railroad—					
Relocation of line	4·5	Miles	50,000 00	225,000	
Bridge over Grass River	....	....	....	180,000	
Bascule bridge at lock	....	....	....	175,000	
Bridge over Pollys Gut	....	....	....	728,000	
					1,308,000

TABLE I.—ESTIMATE OF COST INTERNATIONAL RAPIDS SECTION—SINGLE-STAGE SCHEME (242)—*Continued*

(As proposed by United States Section)

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
2. Navigation works, etc.—*Con.*					
(*k*) Dredging for navigation only, south channel, Cornwall Island—					
Dredging	533,000	Cu. yd.	0 80	426,000	
Dredging over-depth	94,000	"	0 80	75,000	
Removing old bridge				25,000	
					526,000
(*l*) Road relocation	3·2	Miles	30,000 00	96,000	
					96,000
(*m*) Ferry across canal				25,000	
					25,000
					19,284,000
3. Dikes—					
(*a*) Canadian Shore, from 2 miles west of Aultsville to Bergen Lake—					
Stripping	285,000	Cu. yd.	0 65	185,000	
Earth fill	3,691,000	"	0 75	2,768,000	
Rock fill	25,000	"	2 00	50,000	
Riprap slope protection	79,000	"	3 00	237,000	
					3,240,000
(*b*) Head of Bergen Lake to head of Barnhart Island—					
Stripping	24,000	Cu. yd.	0 65	16,000	
Earth fill	976,000	"	0 75	732,000	
Rock fill	9,800	"	2 00	20,000	
Riprap slope protection	17,400	"	3 00	52,000	
					820,000
(*c*) Head of Barnhart Island to Canadian power house—					
Stripping	74,000	Cu. yd.	0 65	48,000	
Earth fill	1,403,000	"	0 75	1,052,000	
Riprap slope protection	19,700	"	3 00	59,000	
					1,159,000
(*d*) United States shore, Cole Creek to Massena Canal, exclusive—					
Stripping	101,000	Cu. yd.	0 65	66,000	
Earth fill	1,130,000	"	0 75	848,000	
Riprap slope protection	32,600	"	3 00	98,000	
					1,012,000
(*e*) Massena Canal, inclusive to foot of South Sault—					
Stripping	66,000	Cu. yd.	0 65	43,000	
Earth fill	1,121,000	"	0 75	841,000	
Rock fill	50,600	"	2 00	101,000	
Riprap slope protection	18,300	"	3 00	55,000	
					1,040,000
(*f*) Foot of South Sault to Robinson Bay Lock—					
Stripping	104,000	Cu. yd.	0 65	68,000	
Earth fill	2,786,000	"	0 75	2,090,000	
Riprap	20,100	"	3 00	60,000	
					2,218,000
(*g*) Robinson Bay lock to United States power house—					
Stripping	91,000	Cu. yd.	0 65	59,000	
Earth fill	2,203,000	"	0 75	1,652,000	
Riprap	21,100	"	3 00	63,000	
					1,774,000
					11,263,000
4. Drainage, Canadian shore—					
Above Hoople Creek—					
Earth excavation	1,264,000	Cu. yd.	0 35	442,000	
Drops	2			52,000	
Bridges	10			89,000	
Hoople Creek to Bergen Lake—					
Earth excavation	640,000	Cu. yd.	0 35	224,000	
Drop	1			39,000	
Bridges	3			51,000	
					897,000
5. Drainage, United States shore				116,000	
					116,000

TABLE I.—ESTIMATE OF COST INTERNATIONAL RAPIDS SECTION—SINGLE-STAGE SCHEME (242)—*Continued)*

(As proposed by United States Section)

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
6. Protection of Iroquois—					
Dikes, earth fill	1,129,000	Cu. yd.	0 75	847,000	
Riprap slope protection	34,500	"	3 00	104,000	
Ditches, excavation	48,000	"	0 65	31,000	
Sewers and pumps				27,000	
					1,009,000
7. Protection of Morrisburg—					
Dikes, earth fill	515,000	Cu. yd.	0 75	386,000	
Riprap slope protection	14,800	"	3 00	44,000	
Ditches, excavation	8,000	"	0 65	5,000	
Culverts				3,000	
Sewers and pumps				52,000	
					490,000
8. Storm-water pumps, Aultsville and Farran Point				65,000	
					65,000
9. Fourteen-foot lock at head of Bergen lake—					
Earth excavation	140,000	Cu. yd.	0 65	91,000	
Rock	3,000	"	3 50	11,000	
Back fill	174,000	"	0 40	70,000	
Concrete	57,700	"	10 00	587,000	
Gates	4	Sets		58,000	
Operating machinery				70,000	
					887,000
10. Control works, head of Massena Power Canal (exclusive of dikes)—					
Excavation, earth	922,000	Cu. yd.	0 65	599,000	
Excavation, rock	8,100	"	3 50	28,000	
Dredging	96,000	"	0 90	86,000	
Concrete	81,000	"	12 00	972,000	
Foundation contingencies		10%		97,000	
Paving	7,800	Cu. yd.	12 00	94,000	
Gate house	332,000	Cu. ft.	0 25	83,000	
Gates				73,000	
Operating machinery and stop logs				37,000	
					2,069,000
11. Initial channel excavation—					
(a) At Chimney Point—					
Dredging	313,000	Cu. yd.	0 80	250,000	
Dredging, over depth	41,000	"	0 80	33,000	
Dredging, rock	185,000	"	4 25	786,000	
Dredging, rock, over depth	38,000	"	4 25	162,000	
Dredging, removal dike	65,000	"	1 50	98,000	
					1,329,000
(b) Galop Island to below Lotus Island—					
Above Island—					
Dredging, loose	1,685,000	Cu. yd.	0 80	1,348,000	
Dredging, loose, over depth	71,000	"	0 80	57,000	
Dredging, rock, dry	70,000	"	1 75	123,000	
Cut through island—					
Excavation, earth	4,186,000	Cu. yd.	0 65	2,721,000	
Excavation, rock	639,000	"	1 75	1,118,000	
Channel below through cut—					
Excavation, dry, earth	1,359,000	Cu. yd.	0 75	1,019,000	
Excavation, dry, rock	655,000	"	1 75	1,146,000	
Unwatering rock cut				200,000	
Dredging, loose	4,446,000	Cu. yd.	1 25	5,558,000	
Dredging, loose, over depth	96,000	"	1 25	120,000	
Dredging, rock	252,000	"	4 25	1,071,000	
Channel south of Lotus-Lalonde Island—					
Excavation, earth, in coffer	1,072,000	Cu. yd.	0 80	864,000	
Excavation, rock, in coffer	329,000	"	1 75	576,000	
Unwatering				502,000	
Dredging	18,000	Cu. yd.	0 90	16,000	
					16,439,000
(c) Sparrowhawk Point—					
Excavation, dry	1,433,000	Cu. yd.	0 65	931,000	
Dredging	742,000	"	1 25	928,000	
Dredging, over depth	36,000	"	1 25	45,000	
					1,904,000

TABLE I.—ESTIMATE OF COST INTERNATIONAL RAPIDS SECTION—SINGLE-STAGE SCHEME (242)—*Continued*

(As proposed by United States Section)

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
11. Initial Channel excavation, etc.—*Con.*					
(*d*) Toussaint Island Cut—					
Excavation, dry	2,744,000	Cu. yd.	0 65	1,784,000	
Dredging	891,000	"	1 25	1,114,000	
Dredging, over depth	46,000	"	1 25	58,000	
					2,956,000
(*e*) Iroquois Point-Point Rockway—					
Excavation, dry	1,135,000	Cu. yd.	0 65	738,000	
Dredging	509,000	"	0 90	458,000	
Dredging, over depth	55,000	"	0 90	50,000	
					1,246,000
(*f*) Point Three Points—					
Excavation, dry	412,000	Cu. yd.	0 65	268,000	
Dredging	931,000	"	0 90	838,000	
Dredging, over depth	68,000	"	0 90	61,000	
					1,167,000
(*g*) Ogden Island—					
North channel—					
Excavation, dry	281,000	Cu. yd.	0 65	183,000	
Dredging	1,006,000	"	0 90	905,000	
Dredging, over depth	124,000	"	0 90	112,000	
South channel—					
Dredging	487,000	Cu. yd.	0 90	418,000	
Dredging, over depth	80,000	"	0 90	72,000	
					1,690,000
					26,731,000
12. Enlargement to 95,000 square feet section—					
Sparrowhawk Point—					
Excavation, earth	2,169,000	Cu. yd.	0 65	1,410,000	
Dredging	800,000	"	0 90	720,000	
Iroquois Point–Point Rockway—					
Excavation, earth	3,615,000	"	0 65	2,350,000	
Dredging	625,000	"	0 90	563,000	
Point Three Points—					
Excavation	2,123,000	"	0 65	1,380,000	
Dredging	373,000	"	0 90	336,000	
Ogden Island—					
North Channel—					
Excavation, earth	2,225,000	"	0 65	1,446,000	
Dredging	541,000	"	0 90	487,000	
South Channel—					
Excavation, earth	2,503,000	"	0 65	1,627,000	
Dredging	1,160,000	"	0 90	1,044,000	
					11,363,000
13. Enlargements at Cornwall Island—					
North channel—					
Earth excavation	800,000	Cu. yd.	0 65	520,000	
Dredging	583,000	"	0 80	466,000	
Dredging, over depth	52,000	"	0 80	42,000	
South channel (additional to Item 2 (*k*)—					
Earth excavation	880,000	"	0 65	572,000	
Dredging	3,174,000	"	0 80	2,539,000	
Dredging over depth	237,000	"	0 80	190,000	
					4,329,000
14. Control dam at Galop—					
Excavation, rock	32,400	Cu. yd.	3 50	114,000	
Concrete	120,000	"	12 00	1,440,000	
Gates	61	....	....	432,000	
Towers and crane tracks	61	Spans	....	142,000	
Service tracks	61	"	....	244,000	
Operating cranes	4	Each	15,000 00	60,000	
Stop logs, fixed parts	....	....	....	24,000	
Stop logs, movable parts	4	Sets	....	39,000	
Cribs	6,200	Cu. yd.	8 00	50,000	
Unwatering	....	....	....	1,610,000	
Removal of Gut Dam	42,000	Cu. yd.	1 50	63,000	
					4,218,000

TABLE I.—ESTIMATE OF COST INTERNATIONAL RAPIDS SECTION—SINGLE-STAGE SCHEME (242)—*Continued)*

(As proposed by United States Section)

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
15. Flowage and damage—					
(a) Canadian shore—					
Chimney Point to Morrisburg—					
Lands				295,000	
Improvements				772,000	
Town property				364,000	
Morrisburg to head of Bergen Lake—					
Land directly required and in severance				1,435,000	
Improvements				1,658,000	
Town property				1,050,000	
					5,574,000
(b) United States shore—					
Chimney Point to Waddington, inclusive—					
Lands				188,000	
Improvements				175,000	
Town property				488,000	
Waddington to Massena Canal—					
Lands				706,000	
Improvements				494,000	
Massena Canal to Massena Point—					
Lands				513,000	
Improvements				335,000	
					2,897,000
(c) Islands—					
Above Long Sault Island—					
Lands				402,000	
Improvements				343,000	
Long Sault Island				265,000	
Barnhart Island				219,000	
Sheek Island				20,000	1,249,000
(d) Power leases				275,000	275,000
					9,995,000
16. Railroad relocation—					
Norwood and St. Lawrence Railroad—					
Track	4·5	Miles	35,000 00	158,000	
Bridges				50,000	
Station				30,000	
Canadian National Railway—					
Track	5·9	Miles	100,000 00	590,000	
Bridges				30,000	
					858,000
17. Highway relocation—					
(a) Canadian shore—					
Johnstown to Morrisburg—					
Roads	10·7	Miles	40,000 00	428,000	
Bridges				25,000	
Morrisburg to Bergen Lake—					
Roads	19	Miles	40,000 00	760,000	
Bridge at Nash Creek				7,000	1,220,000
(b) United States shore—					
Chimney Point to Waddington—					
Raising grade				37,000	
Waddington to Massena Canal—					
Concrete roads (including embankment	7·2	Miles	60,000 00	432,000	
Earth roads	1·5	"	5,000 00	8,000	
Bridges				84,000	
					561,000
					1,781,000

TABLE I.—ESTIMATE OF COST INTERNATIONAL RAPIDS SECTION—SINGLE-STAGE SCHEME (242)—*Continued*

(As proposed by United States Section)

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
18. Clearing reservoir site	5,800	Acres	100 00	580,000	580,000
Net total					209,189,000
Engineering, administration, and contingencies		12½%			26,148,000
					235,337,000

SUMMARY

Item	Net cost	Overhead	Total
	$	$	$
1. Dam and power houses at foot of Barnhart Island	113,254,000	14,157,000	127,411,000
2. Navigation works (channels 25 feet deep)	19,284,000	2,411,000	21,695,000
3. Dikes	11,263,000	1,408,000	12,671,000
4. Drainage, Canadian shore	897,000	112,000	1,009,000
5. Drainage, United States shore	116,000	15,000	131,000
6. Protection of Iroquois	1,009,000	126,000	1,135,000
7. Protection of Morrisburg	490,000	61,000	551,000
8. Storm-water pumps, Aultsville and Farran Point	65,000	8,000	73,000
9. Fourteen-foot lock at head of Bergen Lake	887,000	111,000	998,000
10. Control works,head of Massena Power Canal (exclusive of dikes)	2,069,000	259,000	2,328,000
11. Initial channel excavation	26,731,000	3,341,000	30,072,000
12. Enlargement to 95,000 square foot section	11,363,000	1,420,000	12,783,000
13. Enlargements at Cornwall Island	4,329,000	541,000	4,870,000
14. Control Dam at Galop	4,218,000	527,000	4,745,000
15. Flowage and damage	9,995,000	1,249,000	11,244,000
16. Railroad relocation	858,000	107,000	965,000
17. Highway relocation	1,781,000	223,000	2,004,000
18. Clearing reservoir site	580,000	72,000	652,000
	209,189,000	26,148,000	235,337,000

TABLE I.—ESTIMATE OF COST INTERNATIONAL RAPIDS SECTION—SINGLE-STAGE SCHEME (242)—*Continued*)

(As proposed by United States Section)

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
FOR OTHER CHANNEL DEPTHS					
A. Saving if navigation channel is 23 feet deep originally—					
(1) Approach channel above Robinson Bay—					
Excavation saved	104,000	Cu. yd.	0 65	68,000	
(2) Canal prism, Robinson Bay lock to Grass River lock—					
Excavation saved	157,000	"	0 65	102,000	
(3) Approach channel, Grass River lock to river—					
Excavation saved	9,000	"	0 65	6,000	
(4) Dredging for navigation only, south channel, Cornwall Island—					
Dredging saved	224,000	"	0 80	179,000	
Over depth, saved	40,000	"	0 80	32,000	
					387,000
Engineering administration and contingencies		12½%			49,000
Total					436,000

TABLE I.—ESTIMATE OF COST INTERNATIONAL RAPIDS SECTION—SINGLE-STAGE SCHEME (242)—*Continued*

(As proposed by United States Section)

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
B. Additional cost if channels are made 27 feet deep originally—					
(1) Approach channel above Robinson Bay—					
Excavation added	108,000	Cu. yd.	0 65	70,000	
(2) Canal prism, Robinson Bay lock to Grass River lock—					
Excavation added	160,000	"	0 65	104,000	
(3) Approach channel, Grass River lock to river—					
Excavation added	10,000	"	0 65	7,000	
(4) Dredging for navigation only, south channel, Cornwall Island—					
Dredging added	261,000	"	0 80	209,000	
Over depth added	37,000	"	0 80	22,000	
(5) Control dam at Galop—					
Additional gate and pier				38,000	
					450,000
Engineering administration and contingencies		12½%			56,000
Total					506,000
C. Cost of future enlargement from 25-foot depth to 30-foot depth—					
(1) Excavation, above Galop Island—					
Dredging, loose	78,000	Cu. yd.	0 80	60,000	
Dredging, rock	67,000	"	6 45	432,000	
Dredging, rock, over depth	38,000	"	6 45	245,000	
(2) Revision of control works					
(3) Approach channel above Robinson Bay—					
Dredging	231,000	"	0 75	169,000	
Dredging, over depth	46,000	"	0 75	35,000	
(4) Canal prism, Robinson Bay lock to Grass River lock—					
Dredging	393,000	"	0 75	290,000	
Dredging, over depth	80,000	"	0 75	60,000	
(5) Approach channel, Grass River lock to shore—					
Dredging	24,000	"	0 75	18,000	
Dredging, over depth	5,000	"	0 75	4,000	
(6) Dredging for navigation only, south channel at Cornwall Island—					
Dredging	772,000	"	0 75	579,000	
Dredging, over depth	340,000	"	0 75	255,000	
					2,197,000
Engineering, administration and contingencies		12½%			275,000
Total					2,472,000

TABLE 2.—SINGLE-STAGE SCHEME WITH DAM AT HAWKINS POINT

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
1. Dam and power houses at foot of Barnhart Island—					
(a) Dam, except unwatering—					
Excavation, earth	1,435,000	Cu. yd.	0 65	933,000	
Excavation, rock, dry	145,000	"	2 25	326,000	
Concrete	893,800	"	12 00	10,726,000	
Foundation contingencies		10%		1,072,000	
Gates	33	Spans	10,000 00	330,000	
Towers, track, and bridge	33	"	6,800 00	224,000	

TABLE 2.—SINGLE-STAGE SCHEME WITH DAM AT HAWKINS POINT—*Continued*

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
1. Dam and power houses, etc.—*Con.*					
Operating cranes	3	Each	16,000 00	48,000	
Stop logs	4	Sets	12,500 00	50,000	
Tail-race excavation below Dam—					
Dry earth	4,442,000	Cu. yd.	0 65	2,887,000	
Dredging, loose	1,330,000	"	1 25	1,663,000	
					18,279,000
(*b*) Power-house substructures—					
United States power house—					
Excavation, earth, dry	1,907,000	Cu. yd.	0 65	1,240,000	
Excavation, rock, dry	57,600	"	2 25	130,000	
Concrete, below draft-tube floor	346,000	"	10 00	3,466,000	
Concrete, above draft-tube floor	721,800	"	15,00	10,827,000	
Canadian power house—					
Excavation, earth, dry	1,378,000	"	0 65	896,000	
Excavation, rock, dry	57,600	"	2 25	130,000	
Concrete, below draft-tube floor	38,000	"	10 00	380,000	
Concrete, above draft-tube floor	718,500	"	15 00	10,778,000	
					27,847,000
(*c*) Unwatering dam				2,440,000	
					2,440,000
(*d*) Abutments to power bases—					
United States power house—					
Excavation, earth	459,000	Cu. yd.	0 65	298,000	
Excavation, rock	3,000	"	3 50	11,000	
Back fill	339,000	"	0 40	136,000	
Concrete	120,100	"	12 00	1,441,000	
Canadian power house—					
Excavation, earth	276,000	"	0 65	179,000	
Excavation, rock	2,900	"	3 50	10,000	
Back fill	206,000	"	0 40	82,000	
Concrete	69,800	"	12 00	838,000	
					2,995,000
(*e*) Tail-race excavation—					
United States power house—					
Excavation, earth, dry	6,504,000	Cu. yd.	0 65	4,228,000	
Canadian power house—					
Excavation, earth, dry	2,475,000	"	0 65	1,609,000	
Dredging, earth	689,000	"	1 25	861,000	
Dredging, rock	43,600	"	5 00	218,000	
Excavation, dry, rock	122,000	"	1 75	214,000	
					7,130,000
(*f*) Rail connections to power houses—					
Railroad to United States power house, track	2·1	Miles	40,000 00	84,000	
Railroad to Canadian power house, track	2·7	"	40,000 00	108,000	
Bridges				139,000	
					331,000
(*g*) Superstructure and machinery—					
Estimate I, item 1 (*g*)				53,571,000	
					53,571,000
					112,593,000
2. Navigation works (channels 25 feet deep)—					
Estimate I, item 2 (*a*) to (*m*)				19,284,000	
					19,284,000
3. Dykes—					
(*a*) Canadian shore from 2 miles west of Aultsville to Bergen Lake—					
Estimate I, item 3 (*a*)				3,240,000	
					3,240,000
(*b*) Head of Bergen Lake to Head of Barnhart Island—					
Estimate I, item 3 (*b*)				820,000	
					820,000
(*c*) Head of Barnhart Island to Canadian power house—					
Stripping	56,200	Cu. yd.	0 65	37,000	
Earth fill	740,000	"	0 75	555,000	
Riprap slope protection	13,100	"	3 00	39,000	
					631,000

TABLE 2—SINGLE-STAGE SCHEME WITH DAM AT HAWKINS POINT—*Continued*

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
3. Dykes—*Con.*					
(*d*) United States Shore, Cole Creek to Massena Canal, exclusive—					
Estimate I, item 3 (*d*)				1,012,000	1,012,000
(*e*) Massena Canal, inclusive to foot of South Sault—					
Estimate I, item 3 (*e*)				1,040,000	
(*f*) Foot of South Sault to Robinson Bay lock—					
Estimate I, item 3 (*f*)				2,218,000	2,218,000
(*g*) Robinson Bay lock to United States power house—					
Stripping	41,000	Cu. yd.	0 65	27,000	
Earth fill	935,000	"	0 75	701,000	
Riprap slope protection	8,900	"	3 00	27,000	
					755,000
					9,716,000
4 to 18—Estimate I, items 4 to 18, inclusive				65,388,000	65,388,000
Total net cost					206,981,000
Engineering, administration, and contingencies		12½%			25,873,000
					232,854,000

SUMMARY

Item	Net cost	Overhead	Total
	$	$	$
1. Dam and power houses at foot of Barnhart Island	112,593,000	14,074,000	126,667,000
2. Navigation works (channels 25 feet deep)	19,284,000	2,411,000	21,695,000
3. Dikes	9,716,000	1,214,000	10,930,000
4 to 18, inclusive	65,388,000	8,174,000	73,562,000
	206,981,000	25,873,000	232,854,000

TABLE 3.—SINGLE-STAGE SCHEME—WITH DAM AT LONG SAULT SITE

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
1. Dam at Long Sault and power houses at foot of Barnhart Island—					
(*a*) Dam, except unwatering—					
Excavation, earth	1,267,000	Cu. yd.	0 70	887,000	
Excavation, rock	143,000	"	3 50	501,000	
Concrete	716,100	"	12 00	8,593,000	
Foundation contingencies		10%		859,000	
Gates	46	Each	7,100 00	327,000	
Towers, track, and bridge	46	Spans	6,300 00	290,000	
Operating cranes	4	Each	14,000 00	56,000	
Stop logs	6	Sets	4,000 00	24,000	
					11,537,000
(*b*) Powerhouse substructures—					
United States and Canadian power houses—					
Excavation, earth, dry	1,386,000	Cu. yd.	0 65	901,000	
Excavation, rock, dry	299,500	"	2 25	674,000	
Concrete, below draft-tube floor	7,600	"	10 00	76,000	
Concrete above draft-tube floor	1,294,400	"	15 00	19,416,000	
					21,067,000

TABLE 3.—SINGLE-STAGE SCHEME—WITH DAM AT LONG SAULT SITE—*Continued*

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
1. Dam at Long Sault, etc.—*Con.*					
(c) Unwatering dam and power houses—					
Power houses				2,416,000	
Dam				3,527,000	
Diversion cut across Long Sault Island–					
Excavation, earth	2,472,000	Cu. yd.	0 65	1,607,000	
Excavation, rock	125,000	"	1 25	219,000	
Dredging, loose	707,000	"	0 70	495,000	
Concrete, lining	32,000	"	12 00	384,000	
Compensation weir				400,000	
Temporary gates at dam to control diversion				100,000	
					9,148,000
(d) Ice sluice at end of United States power house, including abutments–					
Excavation, earth	479,300	Cu. yd.	0 65	312,000	
Excavation, rock	19,000	"	3 50	67,000	
Concrete	199,900	"	12 00	2,399,000	
Back fill	200,000	"	0 40	80,000	
Gates	4	Each	6,500 00	26,000	
Stop logs	1	Set	8,000 00	8,000	
Operating machinery				20,000	
					2,912,000
(e) Ice sluice at end of Canadian power house—					
Excavation, earth	40,000	Cu. yd.	0 68	26,000	
Excavation, rock	28,400	"	3 50	99,000	
Concrete	109,300	"	12 00	1,312,000	
Gates	4	Each	6,500 00	26,000	
Stop logs	1	Set	8,000 00	8,000	
Operating machinery				20,000	
					1,491,000
(f) Tail-race excavation—					
United States and Canadian power houses—					
Excavation, earth, dry	3,615,000	Cu. yd.	0 65	2,350,000	
Excavation, rock, dry	975,300	"	1 75	1,707,000	
Dredging, loose	374,000	"	1 25	468,000	
					4,525,000
(g) Forebay excavation—					
United States and Canadian power houses—					
Excavation, earth, dry	444,000	Cu. yd.	0 65	289,000	
Enlargement of Little River—					
Excavation, earth	88,000	"	0 65	57,000	
					346,000
(h) Superstructures and machinery—					
United States and Canadian power houses—					
Estimate I, item 1 (g)				53,571,000	
					53,571,000
(i) Rail connections to power houses—					
Railroad to United States power house, track	9	Miles	40,000 00	360,000	
Railroad to Canadian power house track	1 54	"	40,000 00	62,000	
Bridges				139,000	
					561,000
(j) Ice divertor, at head of Little River—					
Excavation, earth	53,000	Cu. yd.	0 75	40,000	
Concrete	29,500	"	12 00	354,000	
Boom	1,800	Lin. ft.	75 00	135,000	
Unwatering				98,000	
Training dike: Earth fill	106,000	Cu. yd.	0 75	80,000	
Riprap	3,800	"	3 00	11,000	
					718,000
					105,876,000
2. Navigation works (channels 25 feet deep)—					
(a) Embankment, South Sault—					
Rock fill	197,000	Cu. yd.	1 00	197,000	
					197,000

TABLE 3.—SINGLE-STAGE SCHEME—WITH DAM AT LONG SAULT SITE—*Continued*

Item	Quantity	Unit	Unit price	Amount	Sub-totals
2. Navigation works, etc.—*Con.*			$ cts.	$	$
(*b*) Channel above upper lock—					
Excavation, earth	1,250,000	Cu. yd.	0 65	813,000	
Concrete, bank protection	2,000	Lin. ft.	9 00	18,000	
Lighting	0·5	Mile	2,000 00	1,000	
					832,000
(*c*) Upper lock (No. 8)—					
Excavation, earth	1,165,000	Cu. yd.	0 75	874,000	
Excavation, rock	17,500	"	3 50	61,000	
Back fill	736,000	"	0 40	294,000	
Concrete	378,100	"	10 00	3,781,000	
Gates	6	Pair		785,000	
Operating machinery				310,000	
Emergency dam				175,000	
Approach walls—					
Concrete	54,400	Cu. yd.	10 00	544,000	
Piling	198,000	Lin. ft.	0 85	168,000	
Office and dwellings				40,000	
					7,032,000
(*d*) Dike, at Robinson Bay—					
Earth fill	96,000	Cu. yd.	0 75	72,000	
Riprap	4,200	"	3 00	13,000	
					85,000
(*e*) Canal prism, upper lock to Grass River lock—					
Excavation, earth	6,194,000	Cu. yd.	0 65	4,026,000	
Concrete bank protection	16,000	Lin. ft.	9 00	144,000	
Lighting	3	Miles	2,000 00	6,000	
					4,176,000
(*f*) Grass River lock (No. 7)—					
Excavation, earth	905,000	Cu. yd.	0 75	679,000	
Excavation, rock	13,900	"	3 50	49,000	
Back fill	588,000	"	0 40	235,000	
Concrete	337,250	"	10 00	3,373,000	
Gates	6	Pair		730,000	
Operating machinery				300,000	
Approach walls—					
Timber cribs	41,200	Cu. yd.	8 00	330,000	
Piling	71,200	Lin. ft.	0 85	61,000	
Concrete	27,000	Cu. yd.	10 00	270,000	
Office and dwellings				40,000	
					6,067,000
(*g*) Approach channel, Grass River lock to river—					
Estimate I, item 2 (*e*)				227,000	
					227,000
(*h*) Dike at Grass River lock—					
Estimate I, item 2 (*f*)				307,000	
					307,000
(*i*) Waste weir at Grass River lock—					
Estimate I, item 2 (*g*)				757,000	
					757,000
(*j*) Drainage ditch, north of Grass River lock—					
Estimate I, item 2 (*h*)				2,000	
					2,000
(*k*) Diversion dike and flood channel at mouth of Grass River—					
Estimate I, item 2 (*i*)				308,000	
					308,000
(*l*) Diversion of Ottawa Branch, New York Central Railroad—					
Estimate I, item 2 (*j*)				1,308,000	
					1,308,000
(*m*) Dredging for navigation only, south channel, Cornwall Island—					
Estimate I, item 2 (*k*)				526,000	
					526,000
(*n*) Road relocation				117,000	
					117,000
(*c*) Ferry across canal				25,000	
					25,000
					21,966,000

TABLE 3—SINGLE-STAGE SCHEME—WITH DAM AT LONG SAULT SITE—*Continued*

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
3. Dikes—					
(a) Canadian shore, from 2 miles west of Aultsville to Bergen Lake—					
Estimate I, item 3 (a)	......	......	......	3,240,000	
					3,240,000
(b) Head of Bergen Lake to foot of Sheek Island—					
Stripping	97,000	Cu. yd.	0 65	63,000	
Fill, earth	2,045,000	"	0 75	1,534,000	
Fill, rock	15,000	"	2 00	30,000	
Riprap	22,100	"	3 00	66,000	
					1,693,000
(c) Foot of Sheek Island to spillway at Little River—					
Stripping	323,000	Cu. yd.	0 65	210,000	
Fill, earth	7,191,000	"	0 75	5,399,000	
Fill, rock	149,000	"	0 50	75,000	
Riprap	19,300	"	3 00	58,000	
					5,742,000
(d) United States shore, Cole Creek to Massena Canal, exclusive—					
Estimate I, item 3 (d)	......	......	......	1,012,000	
					1,012,000
(e) Massena Canal to Long Sault dam—					
Stripping	35,000	Cu. yd.	0 65	23,000	
Earth fill	730,000	"	0 75	548,000	
Riprap	17,000	"	3 00	51,000	
					622,000
(f) Long Sault dam to United States power house—					
Stripping	59,000	Cu. yd.	0 65	38,000	
Earth fill	1,240,000	"	0 75	930,000	
Riprap	20,400	"	3 00	61,000	
					1,029,000
					13,338,000
4 to 14. Estimate I, items 4 to 14, inclusive	......	......	......	52,174,000	
					52,174,000
15. Flowage and damage—					
(a) Canadian shore—					
Estimate I, item 15 (a)	......	......	......	5,574,000	
Lands	160	Acres	1,000 00	160,000	
					5,734,000
(b) United States shore—					
Chimney Point to Waddington, inclusive—					
Estimate I, item 15 (b)	......	......	......	849,000	
Waddington to Massena Canal—					
Estimate I, item 15 (c)	......	......	......	1,200,000	
Massena Canal to Massena—					
Lands	......	......	......	514,000	
Seepage	......	......	......	25,000	
Severance	1,720	Acres	155 00	267,000	
					2,855,000
(c) Islands—					
Above Galop Island—					
Estimate I, item 15 (c)	......	......	......	745,000	
Long Sault Island—					
Estimate I, item 15 (c)	......	......	......	265,000	
Barnhart Island—					
Estimate I, item 15 (c)	......	......	......	219,000	
Sheek Island—					
Lands	1,225	Acres	149 00	183,000	
Seepage	......	......	......	25,000	
					1,437,000
(d) Power leases	......	......	......	275,000	
					275,000
					10,301,000
16. Railroad relocation—					
Estimate I, item 16	......	......	......	858,000	
					858,000

TABLE 3.—SINGLE-STAGE SCHEME—WITH DAM AT LONG SAULT SITE—*Continued*

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
17. Highway relocation— United States and Canadian shores— Estimate I, item 17 *(a)* and *(b)*				1,781,000	1,781,000
18. Clearing reservoir site	5,600	Acres	100 00	560,000	560,000
Net total					206,854,000
Engineering, administration, and contingencies		12½%			25,857,000
					232,711,000

SUMMARY

Item	Net cost	Overhead	Total
	$	$	$
1. Dam at Long Sault and power houses at foot of Barnhart Island	105,876,000	13,234,000	119,110,000
2. Navigation works (channel 25 feet deep)	21,966,000	2,746,000	24,712,000
3. Dikes	13,338,000	1,667,000	15,005,000
4 to 14, inclusive (*see* Summary, estimate I)	52,174,000	6,522,000	58,696,000
15. Flowage and damage	10,301,000	1,288,000	11,589,000
16. Railroad relocation	858,000	107,000	965,000
17. Highway relocation	1,781,000	223,000	2,004,000
18. Clearing reservoir site	560,000	70,000	630,000
	206,854,000	25,857,000	232,711,000

Item	Quantity	Unit	Unit price	Amount	Sub-totals
			$ cts.	$	$
FOR OTHER CHANNEL DEPTHS					
A. Saving if navigation channel is 23 feet deep originally—					
(1) Approach channel above upper lock— Excavation saved	153,000	Cu. yd.	0 65	99,000	
(2) Canal prism, upper lock to Robinson Bay lock— Excavation saved	483,000	"	0 65	314,000	
(3) Approach channel, Grass River lock to river— Estimate I, item A (3)				6,000	
(4) Dredging, for navigation only, south channel, Cornwall Island— Estimate I, item A (4)				211,000	630,000
Engineering, administration and contingencies		12½%			79,000
Total					709,000
B. Additional cost if channels are made 27 feet deep originally—					
(1) Approach channel above upper lock— Excavation added	149,000	Cu. yd.	0 65	97,000	
(2) Canal prism, upper lock to Robinson Bay lock— Excavation added	470,000	"	0 65	306,000	
(3) to (5), inclusive— Estimate I, items B (3) to (5)				276,000	679,000
Engineering, administration and contingencies		12½%			85,000
Total					764,000

TABLE 3.—SINGLE-STAGE SCHEME—WITH DAM AT LONG SAULT SITE—*Continued*

Item	Quantity	Unit	Unit Price	Amount	Sub-Totals
			$ cts.	$	$
FOR OTHER CHANNEL DEPTHS—*Con.*					
C. Cost of future enlargement from 25-foot depth to 30-foot depth—					
(1) Excavation above Galop Island—					
Estimate I, item C (1)	....	....	....	737,000	
(2) Revision of control works—					
Estimate I, item C (2)	....	....	....	50,000	
(3) Approach channel above upper lock—					
Dredging	364,000	Cu. yd.	0 75	273,000	
Dredging, over depth	72,000	"	0 75	54,000	
(4) Canal prism, upper lock to Grass River lock—					
Dredging	1,144,000	Cu. yd.	0 75	858,000	
Dredging, over depth	229,000	"	0 75	172,000	
(5) and (6)—					
Estimate I, item C (5) and (6)	....	....	....	856,000	
					3,000,000
Engineering, administration and contingencies	....	12½%	....	....	375,000
Total	....	....	....	....	3,375,000

TABLE No. 4.—INTERNATIONAL RAPIDS SECTION—DETAILED ESTIMATE OF TWO-STAGE DEVELOPMENT—224

See Plates Nos. 26–33

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
UPPER POOL, WORKS SOLELY FOR NAVIGATION—			$ cts.		$	$
1. Approach Channels—Ogden Island Lock	Excavation—Dry earth	Cu. yd.	0 65	477,070	310,100	
	Dredging	"	0 90	1,048,000	943,200	
	Overdepth	"	0 90	96,500	86,850	1,340,150
1A. Guide Pier in South Galop	Cribwork	Cu. yd.	5 00	6,000	30,000	30,000
2. Ogden Island Lock and Entrance Piers	Concrete	Cu. yd.	10 00	375,580	3,755,800	
	Cribwork	"	5 00	38,000	190,000	
	Excavation—Earth	"	0 65	1,064,640	692,120	
	Dry rock	"	1 60	3,380	5,410	
	Trench rock	"	4 10	1,900	7,790	
	Close drilling	s.i.	0 45	4,510	2,030	
	Gates and operating machinery				688,000	
	Valves and operating machinery				100,000	
	Fenders, capstans, lighting equipment, etc				181,700	
	Emergency gate				175,000	
	Operating buildings, etc				25,000	5,822,850
						7,193,000
3. Engineering and contingencies	12½ per cent					900,000
4. Total						8,093,000
UPPER POOL, WORKS COMMON TO NAVIGATION AND POWER—						
5. Channel Excavation—						
(a) Chimney Point	Excavation—Wet rock	Cu. yd.	4 25	155,800	662,150	
	Wet rock overdepth	"	4 25	24,700	104,980	
	Dredging	"	0 90	288,400	205,560	
	Dredging overdepth	"	0 90	26,790	24,110	996,800
(b) Removal of Spencer Island Pier	Excavation	Cu. yd.	1 50	123,950	185,930	185,930
(c) Removal of Gut Dam	Excavation	Cu. yd.	1 50	44,640	66,960	66,960
(d) Removal of Centre Wall of Lock 27 and 28 and Canal Bank	Excavation—Masonry and Crib work	Cu. yd.	1 60	14,630	23,410	
	Dredging	"	0 90	167,670	150,900	
	Dredging overdepth	"	0 90	13,330	12,000	186,310
(e) North Galop Channel to below Baycraft Island	Excavation—Dry earth	Cu. yd.	0 65	3,318,860	2,157,260	
	Dry rock	"	1 60	265,660	425,060	

	Dredging	"	0 90	2,189,360	1,970,430	
	Dredging overdepth	"	0 90	137,030	123,330	
	Wet rock	"	4 25	233,800	993,650	
	Wet rock overdepth	"	4 25	60,740	258,150	5,927,880
(f) South Galop Channel—from Butternut Island to South of Baycraft Island	Excavation—Dry earth	Cu. yd.	0 65	429,430	279,120	
	Dry rock	"	1 60	2,506,630	4,010,610	
	Dredging	"	0 90	199,940	179,950	
	Dredging overdepth	"	0 90	31,480	28,340	
	Unwatering—Banks—Earth fill	"	0 60	105,690	63,420	
	Rock fill	"	1 00	91,540	91,540	
	Stripping	"	0 90	20,000	18,000	
	Cofferdams and pumping	"			1,250,000	5,920,980
(g) South of Baycraft Island to below Lotus Island	Excavation—Dry earth	Cu. yd.	0 65	297,990	193,690	
	Dry rock	"	1 60	230,670	369,070	
	Dredging	"	0 90	2,492,780	2,243,510	
	Dredging overdepth	"	0 90	156,000	140,400	2,946,670
(h) South of Lalone Island	Excavation—Dry earth	Cu. yd.	0 65	289,200	187,980	
	Dry rock	"	1 60	263,200	421,120	609,100
(j) Sparrow hawk Point	Excavation—Dredging	Cu. yd.	0 90	2,880,420	2,592,380	
	Dredging overdepth	"	0 90	124,070	111,660	
	Dry earth	"	0 65	1,490,790	969,010	3,673,050
(k) Galop Canal Bank, Presqu'isle and Toussaints Islands	Excavation—Dredging	Cy. yd.	0 90	2,435,870	2,192,280	
	Dredging overdepth	"	0 90	121,730	109,560	
	Dry earth	"	0 65	324,770	211,100	2,512,940
(l) Above Lock 25 to River at Iroquois	Excavation—Earth	Cu. yd.	0 65	39,470	25,660	25,660
(m) Point Rockway	Excavation—Dry earth	Cu. yd.	0 65	691,330	449,360	
	Dredging	"	0 90	1,620,450	1,458,400	
	Dredging overdepth	"	0 90	81,500	73,350	1,981,110
(n) Point Three Points	Excavation—Dredging	Cu. yd.	0 90	2,327,810	2,095,030	
	Dredging overdepth	"	0·90	137,770	124,000	
	Dry earth	"	0 65	204,970	133,230	2,352,260
(o) Channel from Above Point Rockway to below Point Three Points.	Excavation—Dredging	Cu. yd.	0·90	694,520	625,070	
	Dredging overdepth	"	0 90	65,000	58,500	
	Dry earth	"	0 65	2,088,480	1,357,510	
	Dry earth	"	0 40	3,900,000	1,560,000	3,601,080
(p) Leishman's Point	Excavation—Dredging	Cu. yd.	0 90	70,770	63,690	
	Dredging overdepth	"	0 90	6,110	5,500	
	Dry earth	"	0 65	622,870	404,870	474,060
Carried forward						31,460,790

TABLE No. 4—INTERNATIONAL RAPIDS SECTION—DETAILED ESTIMATE OF TWO-STAGE DEVELOPMENT—224—*Continued*

See Plates Nos. 26–33

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						31,460,790
UPPER POOL WORKS COMMON TO NAVIGATION AND POWER—*Con.*						
5. Channel Excavation—*Con.*						
(*q*) North End of Ogden Island	Excavation—Dredging	Cu. yd.	0 90	530,050	477,050	
	Dredging overdepth	"	0 90	37,000	33,300	
	Dry earth	"	0 65	64,800	42,120	552,470
(*r*) Morrisburg Canal Bank	Excavation—Dredging	Cu. yd.	0 90	1,126,530	1,013,880	
	Dredging overdepth	"	0 90	75,700	68,130	
	Masonry	"	1 60	13,770	22,030	1,104,040
(*s*) South side of Ogden Island	Excavation—Dredging	Cu. yd.	0 90	24,170	21,750	
	Dredging overdepth	"	0 90	6,670	6,000	
	Dry earth	"	0 65	1,638,090	1,064,760	
	Dry rock	"	1 60	219,000	350,400	
	Unwatering				402,500	1,845,410
(*t*) Channel through Ogden Island	Excavation—Wet rock	Cu. yd.	4 25	125,350	532,740	
	Wet rock overdepth	"	4 25	17,200	73,100	
	Dry rock	"	1 60	209,250	334,800	
	Dry earth	"	0 65	3,309,080	2,150,900	
	Dredging	"	0 90	150,670	135,610	3,227,150
6. Rock fill Islands above Galop Island	Rock Fill	Cu. yd.	0 40	269,600	107,840	107,840
7 Dam at Head of Channel through Galop Island	Concrete	Cu. yd.	12 00	45,780	549,360	
	Concrete	"	10 00	22,460	224,600	
	Foundation contingency				40,000	
	Excavation—Earth	Cu. yd.	0 65	43,910	28,540	
	Rock (footing)	"	2 40	18,530	44,470	
	Rock (trench)	"	4 10	740	3,040	
	Gates, towers, hoists, etc.				308,700	
	Unwatering				400,000	1,598,710
8. Dam at North End of North Power House	Concrete	Cu. yd.	12 00	30,070	360,840	
	Concrete	"	10 00	10,290	102,900	
	Foundation contingency				25,000	
	Excavation—Earth	Cu. yd.	0 65	72,330	47,020	
	Rock (footing)	"	2 40	7,940	19,060	
	Gates, Towers, Hoists, etc.				94,900	649,720

9. Dam in Bay on North Side of Ogden Island	Concrete	Cu. yd.	12 00	108,580	1,302,960	
	Concrete	"	10 00	69,360	693,600	
	Foundation contingency				70,000	
	Excavation—Rock (footing)	Cu. yd.	2 40	28,060	67,340	
	Rock (trench)	"	4 10	1,930	7,910	
	Earth	"	0 65	542,750	352,790	
	Gates, towers, hoists, etc				337,300	
	Banks—Earth fill	Cu. yd.	0 90	20,830	18,750	
	Rock fill	"	0 60	8,790	5,270	
	Stripping	"	0 65	4,910	3,190	
	Unwatering				300,000	3,159,110
10. Protection to Iroquois	Bank—Earth fill	Cu. yd.	0 90	866,240	779,620	
	Rock fill	"	1 00	252,560	252,560	
	Stripping	"	0 65	214,490	139,420	
	Ditches—Excavation	"	0 65	76,600	49,790	
	Highway and railroad bridges				41,000	
	Sewers and pumping				27,000	1,289,390
11. Property damages—Canadian side	Improvements				648,780	
	Flowage				285,600	
	" orchards				33,000	
	Existing power developments				124,110	1,091,490
12. Property damages—United States side	Improvements				87,000	
	Town property required				435,000	
	Farm lands				168,000	
	" in severance				54,000	744,000
13. Property damages—Islands	Flowage				170,000	
	Improvements				87,000	257,000
14. Highway changes	United States shore				37,000	
	Canadian shore—New roads	Mile	50,000 00	8·7	435,000	
	Bridges				25,000	497,000
15. Clearing pool	United States shore	Acre	100 00	560	56,000	
	Canadian shore	"	100 00	25	2,500	
	Islands	"	100 00	180	18,000	76,500
16. Railroad changes	Can. National Ry. at Iroquois—					
	Relocation	Mile	100,000 00	1·5	150,000	
	Bridges				30,000	180,000
						47,840,620
17. Engineering and contingencies	12½%					5,885,380
18. Total						53,726,000

TABLE No. 4—INTERNATIONAL RAPIDS SECTION—DETAILED ESTIMATE OF TWO-STAGE DEVELOPMENT—224—*Continued*

See Plates Nos. 26–33.

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
UPPER POOL, WORKS PRIMARILY FOR POWER: SUBSTRUCTURES, HEAD AND TAIL-RACE EXCAVATION—						
19. Excavation above North power house	Excavation—Dry earth	Cu. yd.	0 65	888,500	577,530	
	Dredging	"	0 90	1,302,020	1,171,820	
	Dredging, over depth	"	0 90	61,410	55,270	
	Wet rock	"	4 25	94,930	403,450	
	Wet rock, over depth	"	4 25	28,470	121,000	2,329,070
20. Substructure, etc.—North power house	Concrete	Cu. yd.	15 00	532,400	7,986,000	
	Concrete	"	10 00	9,600	96,000	
	Cribwork	"	5 00	52,000	260,000	
	Excavation—Earth	"	0 65	520,150	338,100	
	Rock	"	1 60	554,100	886,560	
	Rock (footings)	"	2 40	400	960	
	Gates and racks				1,831,730	
	Unwatering				2,760,000	14,159,350
21. Substructure, etc.—South power house	Concrete	Cu. yd.	15 00	203,280	3,049,200	
	Concrete	"	10 00	39,800	398,000	
	Excavation—Earth	"	0 65	518,400	336,960	
	Rock	"	1 60	77,880	124,610	
	Rock, trench	"	4 10	1,440	5,900	
	Bank—Earth fill	"	0 90	40,750	36,680	
	Rock fill	"	0 60	16,340	9,800	
	Stripping	"	0 65	8,350	5,430	
	Gates and racks				644,500	4,611,080
						21,099,500
22. Engineering and contingencies	12½%					2,637,500
23. Total						23,737,000
UPPER POOL, WORKS PRIMARILY FOR POWER: MACHINERY AND SUPERSTRUCTURES—						
24. North power house	Generators and turbines—54-5570	H.P. units			15,272,880	
	Switching				2,476,660	
	Cranes and service units				358,540	
	Superstructure				4,050,400	22.158,480
25. South power house	Generators and turbines—19-5570	H.P. units			5,376,060	
	Switching				871,420	

	Cranes and service units				193,140	
	Superstructure				1,470,480	
						7,911,100
						30,069,580
26. Engineering and contingencies	12½%					3,759,420
27. Total						33,829,000
LOWER POOL, WORKS SOLELY FOR NAVIGATION—						
28. Channel excavation—						
(a) Below Clark Island to above Long Sault Island	Excavation—Dredging	Cu. yd.	0 90	104,500	94,050	
	Dredging, over depth	"	0 90	15,250	13,730	
						107,780
(b) Above Long Sault Island to Pobinson Bay lock	Excavation—Dry earth	Cu. yd.	0 65	4,359,540	2,823,700	
	Paving—Concrete	"	11 00	10,770	118,470	
						2,942,170
(c) Robinson Bay lock to Grass River lock	Excavation—Dry earth	Cu. yd.	0 65	2,682,200	1,743,430	
						1,743,430
(d) Grass River lock to shore line	Excavation—Dredging	Cu. yd.	0 80	364,000	291,200	
						291,200
(e) At lower end of Cornwall Island	Excavation—Dredging	Cu. yd.	0 80	307,460	245,970	
	Dredging, over depth	"	0 80	82,030	65,630	
						311,600
(f) At moutn of Grass River	Excavation—Dredging	Cu. yd.	0 80	227,000	181,600	
						181,600
29. Drainage ditch	Excavation—Earth	Cu. yd.	0 65	10,200	6,630	
						6,630
30. Dykes—						
(a) Above Robinson Bay lock	Earth fill	Cu. yd.	0 42	188,210	79,050	
	Earth fill	"	0 60	450,770	270.460	
	Rock fill	"	1 00	49,870	49,870	
	Stripping	"	0 65	117,250	76,220	
	Trimming	Sq. yd.	0 25	98,150	24,540	
	Paving—Concrete	Cu. yd.	11 00	14,300	157,300	
						657,440
(b) Robinson Bay lock to Grass River	Earth fill	Cu. yd.	0 42	669,270	281,090	
	Earth fill	"	0 60	357,250	214,350	
	Stripping	"	0 65	146,510	95,230	
	Trimming	Sq. yd.	0 25	167,010	41,750	
	Sodding	"	0 45	22,000	9,900	
	Paving—Concrete	Cu. yd.	11 00	13,880	152,680	
						795,000
(c) Rock fill—Guide dike below Grass River lock	Pock fill	Cu. yd.	2 00	63,000	126,000	
						126,000
31. Guard gate and supply weir	Concrete	Cu. yd.	12 00	4,520	54,240	
	Concrete	"	10 00	32,730	327,300	
	Founaation contingency				5,400	
	Cribwork	Cu. yd.	5 00	37,030	185,150	
	Excavation—Earth	"	0 65	44,060	28,640	
	Earth, trench	"	3 10	3,340	10,350	
Carried forward						7,162,850

TABLE No. 4—INTERNATIONAL RAPIDS SECTION—DETAILED ESTIMATE OF TWO-STAGE DEVELOPMENT—224—*Continued*

See Plates Nos. 26–33

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						7,162,850
LOWER POOL, WORKS SOLELY FOR NAVIGATION—*Con.*						
31. Guard gate and supply weir—*Con.*	Sheeting and bracing	M ft.b.m.	110 00	65	7,150	
	Lock gates, operating machinery, etc.				120,000	
	Sluice gates, hoists, etc				33,800	772,030
32. Robinson Bay lock—Entrance piers and weir	Concrete	Cu. yd.	10 00	221,640	2,216,400	
	Concrete	"	15 00	92,160	1,382,400	
	Cribwork	"	5 00	73,360	366,800	
	Excavation—Earth	"	0 65	974,140	633,190	
	Lock gates and operating machinery				603,000	
	Lock valves and operating machinery				100,000	
	Emergency gate				175,000	
	Fenders, capstans, lighting equipment, etc				206,700	
	Sluice gates, hoists, etc				52,690	5,736,180
33. Regulating weir at Robinson Bay	Concrete	Cu. yd.	12 00	13,200	158,400	
	Concrete	"	10 00	22,190	221,900	
	Foundation contingency				15,840	
	Excavation—Rock, footings	Cu. yd.	2 40	2,970	7,130	
	Rock, trench	"	4 10	450	1,850	
	Earth	"	0 65	348,360	226,430	
	Unwatering				35,650	
	Sluice gates, hoists, etc				30,800	698,000
34. Grass River lock and entrance piers	Concrete	Cu. yd.	10 00	351,060	3,510,600	
	Excavation—Earth	"	0 65	1,296,950	843,020	
	Cribwork	"	5 00	76,050	380,250	
	Lock gates and operating machinery				845,600	
	Lock valves and operating machinery				100,000	
	Fenders, capstans, lighting equipment, etc				206,700	5,886,170
35. N.Y.C. Ry. diversion and bridges	Bridge over Polly's Gut				728,000	
	" canal				175,000	
	" Grass River				180,000	
	Railroad relocation	Mile	50,000 00	4·5	225,000	1,308,000
36. Canal lighting and office					16,000	16,000

37. Clearing pool	Clearing	Acre	100 00	150	15,000	15,000
38. Roads	Diversion	Mile	30,000 00	1·25	37,500	
	Improvements	"	3,000 00	2·73	8,190	
	New	"	30,000 00	2·4	72,000	117,690
39. Property damages	Flowage				330,330	
	Severance				266,600	596,930
						22,308,850
40. Engineering and contingencies	12½% approximately					3,079,150
41. Total						25,388,000
LOWER POOL, WORKS COMMON TO NAVIGATION AND POWER—						
42. Dikes—						
(a) Canadian shore, Wales to Moulinette	Earth fill	Cu. yd.	0 65	170,670	110,940	
	Rock fill	"	0 90	71,560	64,400	
	Stripping	"	0 65	63,690	41,400	216,740
(b) Canadian shore, Mille Roches to power house	Earth fill	Cu. yd.	0 90	778,090	700,280	
	Rock fill	"	0 65	246,750	160,390	
	Stripping	"	0 65	99,020	64,360	925,030
(c) United States shore, Wilson Hill to Louisville Landing	Earth fill	Cu. yd.	0 90	13,280	11,950	
	Rock fill	"	1 00	6,000	6,000	
	Stripping	"	0 65	7,580	4,930	22,880
(d) West and east of Massena Canal	Earth fill	Cu. yd.	0 90	224,620	202,160	
	Rock fill	"	1 00	78,800	78,800	
	Stripping	"	0 65	60,960	39,630	320,590
(e) Between Massena Canal and Navigation Canal	Earth fill	Cu. yd.	0 65	7,130	4,630	
	Rock fill	"	1 00	3,140	3,140	
	Stripping	"	0 65	4,680	3,040	10,810
(f) East and west end of Long Sault Dam	Earth fill	Cu. yd.	0 90	81,280	73,150	
	Rock fill	"	0 65	25,340	16,470	
	Stripping	"	0 65	10,330	6,720	96,340
(g) On Barnhart Island	Earth fill	Cu. yd.	0 90	181,860	163,680	
	Rock fill	"	0 65	65,770	42,750	
	Stripping	"	0 65	37,520	24,390	230,820
43. Channel excavation—						
(a) Canada Island to Long Sault Island	Excavation—Dry earth	Cu. yd.	0 65	1,211,300	787,350	
	Dredging	"	0 90	1,438,120	1,294,310	
	Dredging, over depth	"	0 90	86,570	77,920	2,159,580
Carried forward						3,982,790

TABLE No. 4.—INTERNATIONAL RAPIDS SECTION—DETAILED ESTIMATE OF TWO-STAGE DEVELOPMENT—224—*Continued*

See Plates Nos. 26–33

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						3,982,790
LOWER POOL, WORKS COMMON TO NAVIGATION AND POWER—*Con.*						
43. Channel excavation—*Con.*						
(*b*) North side of Cornwall Island	Excavation—Dry earth	Cu. yd.	0 65	800,000	520,000	
	Dredging	"	0 80	582,560	466,050	
	Dredging, over depth	"	0 80	52,000	41,600	1,027,650
(*c*) South side of Cornwall Island	Excavation—Dry earth	Cu. yd.	0 65	618,270	401,880	
	Dredging	"	0 80	2,932,360	2,345,890	
	Dredging, over depth	"	0 80	218,010	174,410	2,922,180
44. Supply channel and weir at Massena Canal	Concrete	Cu. yd.	12 00	19,260	231,120	
	Concrete	"	10 00	31,150	311,500	
	Foundation contingency				23,160	
	Excavation—Rock footings	Cu. yd.	2 40	4,590	11,020	
	Rock, trench	"	4 10	870	3,570	
	Earth	"	0 65	870,960	566,120	
	Dredging	"	0 90	43,000	38,700	
	Dredging, over depth	"	0 90	3,000	2,700	
	Paving—Concrete	"	11 00	6,550	72,050	
	Sluice gates, hoists, etc				75,700	1,335,640
45. Diversion cut through Long Sault Island	Excavation—Dry earth	Cu. yd.	0 65	2,172,420	1,412,070	
	Dry rock	"	1 60	29,110	46,580	
	Dredging	"	0 90	287,900	259,110	
	Dredging, over depth	"	0 90	29,600	26,640	
	Paving—Concrete	"	11 00	28,270	310,970	2,055,370
46. Main Long Sault Dam	Concrete	Cu. yd.	12 00	498,470	5,981,640	
	Concrete	"	10 00	39,260	392,600	
	Foundation contingency				598,200	
	Excavation—Earth	Cu. yd.	0 65	908,730	590,670	
	Rock, footings	"	2 40	105,300	252,720	
	Rock, trench	"	4 10	780	3,200	
	Gates, towers, hoists, etc				646,060	
	Unwatering				3,700,000	12,165,090
47. Drainage—						
(*a*) Ditches, etc., Wales to Moulinette	Excavation	Cu. yd.	0 65	378,740	246,180	
	Bridges				30,000	
	Pump station				18,000	294,180

(b) Sewer for paper mill at Mille Roches	Trench excavation	Cu. yd.	3 10	18,410	57,070	
	Sheeting and bracing	M. ft.b.m	110 00	497	54,670	
	Supplying and laying 24-in. pipe	Feet	4 00	15,000	60,000	171,740
8. 14-ft. lock, entrance piers and weir at Mille Roches	Concrete	Cu. yd.	12 00	13,750	165,000	
	Concrete	"	10 00	131,130	1,311,300	
	Foundation contingency				16,500	
	Cribwork	Cu. yd.	5 00	3,160	15,800	
	Excavation—Earth	"	0 90	219,510	197,560	
	Rock, footings	"	2 40	2,970	7,130	
	Rock, trench	"	4 10	1,160	4,760	
	Lock gates, valves, operating machinery, etc				82,000	
	Sluice gate, hoists, etc				30,800	1,830,850
49. Railroad changes	United States side, Norwood and St. L. Railroad—Relocation	Mile	35,000 00	2	70,000	
	Norwood and St. L. Railroad—Bridges				22,000	
	Canadian side C.N. Ry.—Relocation	Mile	100,000 00	3·7	370,000	462,000
50. Clearing pool		Acre	100 00	1,610	161,000	161,000
51. Highway changes	United States shore—Roads				265,000	
	Bridges				50,000	
	Canadian shore—Roads				823,500	
	Bridges				85,000	1,223,500
52. Property damages—United States side	Improvements				572,000	
	Flowage—United States shore				116,220	
	United States shore				327,600	
	Long Sault Island				179,520	
	Barnhart Island				219,120	
	Other islands				160,430	
	Severance				4,000	
	Seepage				36,000	1,614,890
53. Property damages—Canadian side	Improvements				2,615,720	
	Flowage—Canadian shore				627,800	
	Orchards				41,250	
	Sheek Island				52,800	
	Existing power developments				149,160	3,486,730
54. Protection to Morrisburg	Bank—Earth fill	Cu. yd.	0 90	78,180	70,360	
	Rock fill	"	1 00	35,490	35,490	
	Stripping	"	0 65	27,650	17,970	
	Drainage Ditch—Excavating—Earth	"	0 65	8,000	5,200	
	Sewers and pumping				52,000	181,020
						$ 32,914,630
55. Engineering and contingencies	12½% approximately					4,215,370
56. Total						$ 37,130,000

TABLE No. 4.—INTERNATIONAL RAPIDS SECTION—DETAILED ESTIMATE OF TWO-STAGE DEVELOPMENT—224—*Continued*

See Plates Nos. 26-33

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
LOWER POOL, WORKS PRIMARILY FOR POWER: SUBSTRUCTURES, HEAD AND TAIL-RACE EXCAVATION—						
57. Head and Tail-race excavation..						
(a) Removal of Upper and Lower Sheek Isd. dams	Excavation—Earth	Cu. yd.	0 90	249,020	224,120	
	Masonry	"	4 25	530	2,260	226,380
(b) Tail-race	Excavation—Dry earth	Cu. yd.	0 65	3,266,580	2,123,280	
	Dry rock	"	1 60	1,208,340	1,933,340	
	Dredging	"	0 90	3,120,570	2,808,520	
	" over depth	"	0 90	281,000	252,900	7,118,040
58. Spillway North of Power House	Concrete	Cu. yd.	12 00	68,880	826,560	
	Concrete	"	10 00	106,350	1,063,500	
	Foundation contingency				80,000	
	Excavation—Earth	Cu. yd.	0 65	31,080	20,200	
	Rock footings	"	2 40	14,100	33,840	
	Trench	"	4 10	2,190	8,980	2,033,080
59. Ice Sluices at South end of Power House	Concrete	Cu. yd.	12 00	91,130	1,093,560	
	Concrete	"	10 00	60,090	600,900	
	Foundation contingency				100,000	
	Excavation—Earth	Cu. yd.	0 65	1,106,260	719,070	
	Rock footings	"	2 40	13,500	32,400	
	" trench	"	4 10	490	2,010	
	Gates, towers, hoists, etc.				74,000	2,621,940
60. Power House substructure, etc.	Concrete	Cu. yd.	15 00	1,002,440	15,036,600	
	Gates, racks, etc.				3,592,260	
	Unwatering				1,905,230	20,534,090
61. Railway Spur to Power House	Bridges				248,000	
	Railway spur				70,000	318,000
						$ 32,851,530
62. Engineering and contingencies	12½% approximately					4,014,470
63. Total						$ 36,866,000

Lower Pool, Works Primilarly for Power: Machinery and Suprrstructure—						
64. Barnhart Island power house	Generators and turbines 38–47,600 H.P. units				27,208,000	
	Switching				8,139,600	
	Cranes and service units				495,420	
	Super structure				4,847,200	
						40,690,220
65. Engineering and contingencies	12½%					5,086,780
66. Total						$ 45,777,000

TABLE NO. 4.—INTERNATIONAL RAPIDS SECTION—DETAILED ESTIMATE OF TWO-STAGE DEVELOPMENT—224—*Continued*

See Plates No. 26–33

Item and description	Classification	Unit	Rate	Saving if navigation channels made 23 ft. deep originally		Additional cost if navigation channels made 27 ft. deep originally		Cost of future enlargement from 25 ft. depth to 30 ft. depth	
				Quantity	Amount	Quantity	Amount	Quantity	Amount
			$ cts.		$		$		$
67. Chimney Point to above Ogden Island	Excavation—Wet rock	Cu. yd.	5 00	....	....	....	....	628,000	3,140,000
	Wet rock over depth	"	5 00	....	....	....	....	207,000	1,038,500
	Dredging	"	0 90	....	....	....	....	213,200	191,880
	Dredging over depth	"	0 90	....	....	....	....	31,480	28,330
68. Approach channels to Ogden Island lock	Excavation—Dry earth	"	0 65	54,220	35,240	54,220	35,240	....	....
	Dredging	"	0 90	193,000	173,700	192,000	172,800	617,540	555,790
	Dredging over depth	"	0 90	....	....	....	....	120,900	108,810
69. Below Clark Island to above Long Sault Island	Excavation—Dredging	"	0 90	32,110	28,900	47,700	42,930	130,900	117,810
	Dredging over depth	"	0 90	3,710	3,340	7,250	6,520	40,260	36,230
70. Above Long Sault Island to Robinson Bay lock	Excavation—Dry earth	"	0 65	257,690	167,500	252,790	164,310	....	....
	Dredging	"	0 90	....	....	....	....	616,160	554,540
	Dredging over depth	"	0 90	....	....	....	....	126,400	113,760
71. Robinson Bay lock to Grass River lock	Excavation—Dry earth	"	0 65	270,000	175,500	260,000	169,000	....	....
	Dredging	"	0 90	....	....	....	....	630,000	567,000
	Dredging over depth	"	0 90	....	....	....	....	120,000	108,000
72. Grass River lock to Shore line	Excavation—Dry earth	"	0 65	9,000	5,850	10,000	6,500	....	....
	Dredging	"	0 80	....	....	....	....	24,000	19,200
	Dredging over depth	"	0 80	....	....	....	....	6,000	4,800
73. Lower end of Cornwall Island	Excavation—Dredging	"	0 80	177,960	142,370	214,540	171,630	522,240	417,790
	Dredging over depth	"	0 80	66,580	53,260	17,970	14,380	344,400	275,520
				....	785,660	....	783,310	....	7,277,960
74. Engineering and contingencies	12½% approximately	....	....	....	130,340	....	117,690	....	919,040
75. Total	....	....	....	....	916,000	....	901,000	....	8,197,000

TABLE NO. 4.—INTERNATIONAL RAPIDS SECTION—DETAILED ESTIMATE OF TWO-STAGE DEVELOPMENT—224—*Continued*

SUMMARY

———	Item No.	Amount	Total
		$	$
Upper Pool—Works solely for navigation	4	8,093,000	
Works common to navigation and power	18	53,726,000	
Works primarily for power:—			
Substructure, head and tail—Race excavation	23	23,737,000	
Machinery and superstructures	27	33,829,000	
			119,385,000
Lower pool—Works solely for navigation	41	25,388,000	
Works common to navigation and power	56	37,130,000	
Works primarily for power:—			
Substructures, head and tail—Race excavation	63	36,866,000	
Machinery and superstructure	66	45,777,000	
			145,161,000
Total			264,546,000
Rounded Total			264,600,000
Estimated initial expenditure to open navigation and provide 406,400 horse-power in upper plant, and 756,600 horse-power in lower plant. (Remaining installation at lower plant deferred awaiting growth of market)			238,400,000
Estimated initial expenditure to open navigation and provide 1,163,000 horse-power at lower plant. (Remaining installation lower plant and all that of upper plant being deferred)			214,500,000
Saving if navigation channels made 23 feet deep originally	75		916,000
Additional cost if navigation channels made 27 feet deep originally	75		901,000
Cost of future enlargement from 25 foot depth to 30 foot depth	75		8,197,000

TABLE No. 5—INTERNATIONAL RAPIDS SECTION—CRYSLER ISLAND—TWO-STAGE DEVELOPMENT—217

See Plates Nos. 34—38

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
UPPER POOL—WORKS SOLELY FOR NAVIGATION—						
1. Guide pier in south galop	Cribwork	Cu. yd.	5 00	6,000	30,000	30,000
2. Approach channels—Bradford Pt. Lock and Dykes	Excavation—Dry earth	Cu. yd.	0 65	2,526,490	1,642,220	
	Dredging	"	0 90	231,230	208,110	
	Over depth	"	0 90	30,000	27,000	
	Earth fill	"	0 90	627,560	564,800	
	Rock fill	"	1 00	231,330	231,330	
	Stripping	"	0 65	116,560	75,760	2,749,220
3. Bradford Point lock and entrance piers	Concrete	Cu. yd.	10 00	194,960	1,949,600	
	Concrete	"	15 00	60,810	912,150	
	Cribwork	"	5 00	85,000	425,000	
	Excavation—Earth	"	0 65	547,890	356,130	
	Pumping				129,600	
	Gates and operating machinery				728,000	
	Valves and operating machinery				100,000	
	Fenders, capstans, lighting equipment, etc				181,700	
	Emergency gate				175,000	
	Operating buildings, etc				25,000	4,982,180
						$ 7,761,400
Engineering and Contingencies	12½%					970,600
4. Total						$ 8,732,000
UPPER POOL—WORKS COMMON TO NAVIGATION AND POWER:—						
5. Channel excavation—						
(a) Above Chimney Point to below Point Three Points	See Table No. 4—Items No. 5 (a) to 5 (o) inclusive					30,986,730
(b) Leishman's Point	Excavation—Dredging	Cu. yd.	0 90	666,450	599,800	
	Dredging over depth	"	0 90	66,670	60,000	
	Dry earth	"	0 65	329,930	214,450	874,250
(c) Opposite Leishman's Point	Excavation—Dredging	Cu. yd.	0 90	573,130	515,820	
	Dredging over depth	"	0 90	50,000	45,000	
	Dry earth	"	0 65	133,020	86,460	647,280
(d) North and South side of Ogden Island	Excavation—Dry earth	Cu. yd.	0 65	3,174,350	2,063,330	

	Dredging	"	0 90	827,290	744,560	
	Over depth	"	0 90	119,200	107,280	
	Dry rock	"	1 60	65,490	104,780	
	Unwatering				194,930	3,214,880
(e) Morrisburg canal bank	Excavation—Dredging	Cu. yd.	0 90	1,202,230	1,082,010	
	Masonry	"	1 60	13,770	22,030	1,104,040
(f) Canada Island	Excavation—Dry earth	Cu. yd.	0 65	201,300	130,850	
	Dredging	"	0 90	143,700	129,330	
	Over depth	"	0 90	19,000	17,100	
	Rip-rap	"	2 70	5,180	13,990	291,270
6. Rock Fill Islands above Galop Island and Cribs above Point Three Points	Rock fill	Cu. yd.	0 40	269,600	107,840	
	Cribwork	"	5 00	44,300	221,500	329,340
7. Dam at head of channel through Galop Island and dam between Adams Island and Galop Island	Concrete	Cu. yd.	12 00	46,190	554,280	
	Concrete	"	10 00	24,470	244,700	
	Foundation contingency				55,430	
	Excavation—Earth	Cu. yd.	0 65	99,220	64,490	
	Rock footings	"	2 40	9,280	22,270	
	Rock trench	"	4 10	740	3,030	
	Gates, hoists and superstructure				1,336,360	
	Unwatering				491,640	2,772,200
8. Dykes— (a) Canadian side—Crysler Island	Earth fill	Cu. yd.	0 90	562,140	505,930	
	Rock fill	"	1 00	240,760	240,760	
	Stripping	"	0 65	176,510	114,730	861,420
(b) U.S. side—Crysler Island	Earth fill	Cu. yd.	0 90	270,630	333,570	
	Rock fill	"	1 00	148,240	148,240	
	Stripping	"	0 65	97,330	63,260	545,070
9. Provision for 14 ft. navigation	Lock and ent. piers—Concrete	Cu. yd.	10 00	20,740	207,400	
	Cribwork	"	5 00	16,680	83,400	
	Gates, etc				65,000	
	Entrance chan'l—Excavation—Earth	Cu. yd.	0 65	185,560	120,610	
	Paving—Concrete	"	11 00	2,150	23,650	500,060
10. Crysler Island dam	Concrete	Cu. yd.	12 00	475,560	5,706,720	
	Caissons, sheet piling, excavation and unwatering				4,152,500	
	Grouting				200,000	
	Sluice gates, hoists, etc.				645,500	10,704,720
Carried forward						52,831,260

TABLE No. 5—INTERNATIONAL RAPIDS SECTION—CRYSLER ISLAND—TWO-STAGE DEVELOPMENT—217—*Continued*

See Plates Nos. 34-38.

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						52,831,260
UPPER POOL, WORKS COMMON TO NAVIGATION AND POWER—*Con.*						
11. Protection to Towns—						
(a) Iroquois	See Table No. 4—Item No. 10					1,289,390
(b) Morrisburg	Bank—Earth fill	Cu. yd.	0 90	476,480	428,830	
	Rock fill	"	1 00	183,250	183,250	
	Stripping	"	0 65	92,160	59,900	
	Drainage ditch—Excavation—Earth	"	0 65	8,000	5,200	
	Culverts, sewers and pumping				55,000	
	Sewer to below Crysler Island—					
	Trench excavation	Cu. yd.	3 10	147,780	458,120	
	Sheeting and bracing	M.F.B.M.	110 00	2,280	250,800	
	Concrete	Cu. yd.	20 00	8,690	173,800	1,614,900
12. Property Damages—Canadian side	Improvements				1,347,290	
	Flowage				663,000	
	Flowage orchards				48,000	
	Existing Power Developments				124,110	2,182,400
13. Property damages—U.S. Side	Improvements				435,000	
	Town property required				387,000	
	Farm lands				168,000	
	Farm lands				480,000	
	Severance				53,500	
	Severance				12,000	1,535,500
14. Property damages—Islands						523,000
15. Highway changes	U. S. Shore—New roads	Mile	60,000 00	5·4	324,000	
	Bridges				84,000	
	Canadian Shore—New roads	Mile	50,000 00	13·4	670,000	
	Bridges				32,000	1,110,000
16. Clearing Pool	U.S. Shore	Acre	100·00	2,660	266,000	
	Canadian Shore	"	100·00	325	32,500	
	Islands	"	100·00	720	72,000	370,500
17. Railroad changes	Canadian National Ry., at Iroquois—Relocation	Mile	100,000 00	1·5	150,000	
	Bridges				30,000	
	Canadian National east of Morrisburg—Relocation				365,000	

	Norwood and St. Lawrence Rly.—Bridges	Mile	35,000 00	4·5	157,500	
					50,000	
						752,500
						62,209,450
Engineering and contingencies	12½%					7,776,550
18. Total						69,986,000
UPPER POOL—WORKS PRIMARILY FOR POWER:—SUBSTRUCTURES,						
19. Head and Tailrace excavation—North power house	Excavation—Dry earth	Cu. yd.	0·65	868,700	564,660	
	Dredging	"	0·90	1,621,530	1,459,380	
	Over depth	"	0·90	106,500	95,850	
						2,119,890
20. Head and Tailrace excavation—South power house	Excavation—Dry earth	Cu. yd.	0·65	292,890	190,380	
	Dredging	"	0·90	674,360	606,920	
	Over depth	"	0·90	61,100	54,990	
						852,290
21. Power house substructures	Concrete	"	15·00	808,930	12,133,950	
	Gates and racks				2,692,980	
	Unwatering				3,263,120	
						18,090,050
22. Railway connection to power houses	New railway line	Mile	50,000 00	5	250,000	
	Bridge, towers and crane				209,000	
						459,000
23. Ice sluices and walls	Concrete	Cu. yd.	15·00	24,900	373,500	
	Concrete	"	12·00	28,980	347,760	
	Concrete	"	10·00	37,320	373,200	
	Foundation contingency				34,780	
	Excavation—Earth	Cu. yd.	0 65	38,370	24,940	
	Trench earth	"	3 10	25,530	79,140	
	Sheeting and bracing	M.F.B.M.	110 00	198	21,780	
	Gates, hoists, etc				66,300	
						1,321,400
						22,842,630
24. Engineering and contingencies	12½%					2,855,370
25. Total						25,698,000
UPPER POOL—WORKS PRIMARILY FOR POWER:—MACHINERY AND SUPERSTRUCTURE—						
26. Machinery and superstructure	Generators and turbines ·36—16,600 H.P. Units				19,223,100	
	Switching				3,919,860	
	Cranes and service units				533,860	
	Superstructure				3,665,090	
						27,341,910
27. Engineering and contingencies	12½%					3,418,090
28. Total						30,760,000

TABLE No. 5—INTERNATIONAL RAPIDS SECTION—CRYSLER ISLAND—TWO-STAGE DEVELOPMENT—217—*Continued*

See Plates Nos. 34-38

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
LOWER POOL—WORKS SOLELY FOR NAVIGATION—						
29. Channel excavation—						
(a) Morrisburg to above Long Sault Island	Excavation—Dredging	Cu. yd.	0 90	11,850	10,670	
	Dredging over depth	"	0 90	2,960	2,660	
						13,330
(b) Above Long Sault Island to Robinson Bay lock	Excavation—Dry earth	"	0 65	5,894,140	3,831,190	
	Paving—Concrete	"	11 00	21,840	240,240	
						4,071,430
(c) Robinson Bay lock to below Cornwall Island	See Table No. 4.—Items No. 28 (c) to 28 (f)					2,527,830
30. Drainage ditch	Excavation—Earth	Cu. yd.	0 65	10,200	6,630	
						6,630
31. Dykes—						
(a) Above Robinson Bay lock	Earth fill	"	0 42	163,430	68,220	
	Earth fill	"	0 60	131,300	78,780	
	Rock fill	"	1 00	10,870	10,870	
	Stripping	"	0 65	70,840	46,050	
	Trimming	"	0 25	74,070	18,520	
	Paving—Concrete	"	11 00	14,300	157,300	
						379,740
(b) Robinson Bay lock to Grass River	See Table No. 4—Item No. 30 (b)					795,000
(c) Rock fill—Guide dyke below Grass River lock	See Table No. 4.—Item No. 30 (c)					126,000
32. Guard gate and supply weir	Concrete	Cu. yd.	12 00	4,520	54,240	
	Concrete	"	10 00	32,710	327,100	
	Foundation contingency				5,400	
	Cribwork	"	5 00	37,030	185,150	
	Excavation—Earth	"	0 65	44,060	28,640	
	Earth (Tr.)	"	3 10	5,180	16,060	
	Sheet and brace	M.F.B.M.	110 00	86	9,460	
	Lock gate, etc., etc				119,000	
	Sluice gates, etc., etc				33,800	
						778,850
33. Robinson Bay Lock—Entrance piers and weir	Concrete	Cu. yd.	10 00	200,010	2,000,100	
	Concrete	"	15 00	85,000	1,275,000	
	Cribwork	"	5 00	76,750	383,750	
	Excavation—Earth	"	0 65	1,063,570	691,320	
	Lock gates and operating machinery				550,000	
	Lock valves and operating machinery				100,000	
	Emergency gate				175,000	
	Fenders, capstans, lighting equipment, etc				206,700	
	Sluice gates, hoists, etc				52,690	
						5,434,560

34. Regulating weir at Robinson bay	See Table No. 4—Item No. 33					698,000
35. Grass River lock and entrance piers	See Table No. 4—Item No. 34					5,886,170
36. N. Y. Rly. Diversion and bridges	See Table No. 4—Item No. 35					1,308,000
37. Canal lighting and office	See Table No. 4—Item No. 36					16,000
38. Clearing pool	See Table No. 4—Item No. 37					15,000
39. Roads	See Table No. 4—Item No. 38					117,690
40. Property damages	See Table No. 4—Item No. 39					596,930
						22,771,160
41. Engineering and contingencies	12½%					2,846,840
42. Total						25,618,000
LOWER POOL—WORKS COMMON TO NAVIGATION AND POWER—						
43. Dykes—						
(a) Mille Roche to Power House	Earth fill	Cu. yd.	0 90	519,350	467,420	
	Rock fill	"	0 65	169,770	110,350	
	Stripping	"	0 65	74,850	48,660	626,430
(b) West and east of Massena Canal	Earth fill	Cu. yd.	9 90	121,850	109,670	
	Rock fill	"	1 00	37,050	37,050	
	Stripping	"	0 65	14,710	9,560	156,280
(c) Between Massena Canal and Navigation Canal	Earth fill	Cu. yd.	0 65	12,670	8,240	
	Rock fill	"	1 00	5,810	5,810	
	Stripping	"	0 65	5,140	3,340	17,390
(d) On Barnhart island	Earth fill	Cu. yd.	0 90	108,230	97,410	
	Rock fill	"	0 65	39,580	25,730	
	Stripping	"	0 65	22,420	14,570	137,710
44. Channel Excavation—						
(a) Farrans Point, Canal bank and north side of Croil Island	Excavation—Dry earth	Cu. yd.	0 65	265,510	172,580	
	Dredging	"	0 90	1,426,780	1,284,100	
	Dredging, overdepth	"	0 90	84,810	76,330	1,533,010
(b) North side of Long Sault Island	Excavation—Dry earth	Cu. yd.	0 65	217,130	141,130	
	Dredging	"	0 90	315,490	283,940	
	Over depth	"	0 90	22,300	20,070	445,140
(c) North side of Cornwall Island	See Table No. 4—Item No. 43 (b)					1,027,650
(d) South side of Cornwall Island	See Table No. 4—Item No. 43 (c)					2,922,180
45. Supply channel and weir at Massena Canal	Concrete	Cu. yd.	12 00	16,560	198,720	
	Concrete	"	10 00	20,750	207,500	
	Foundation contingency				19,870	
	Excavation—Rock footings	Cu. yd.	2 40	4,320	10,370	
	Rock trench	"	4 10	560	2,300	
	Earth	"	0 65	834,230	542,250	
	Dredging	"	0 90	43,000	38,700	
	Overdepth	"	0 90	3,000	2,700	
Carried forward						6,865,790

TABLE No. 5.—INTERNATIONAL RAPIDS SECTION—CRYSLER ISLAND—TWO-STAGE DEVELOPMENT—217—*Continued*

See Plates Nos. 34-38

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						6,865,790
LOWER POOL—WORKS COMMON TO NAVIGATION AND POWER—*Con.*						
45. Supply channel and weir at Massena Canal	Concrete—Paving	"	11 00	6,550	72,050	
	Sluice gates, hoists, etc				75,700	
						1,170,160
46. Diversion cut through Long Sault Island	See Table No. 4—Item No. 45					2,055,370
47. Main Long Sault dam	Concrete	Cu. yd.	12 00	449,240	5,390,880	
	Concrete	"	10 00	34,880	349,800	
	Foundation contingency				539,090	
	Excavation—Earth	Cu. yd.	0 65	918,160	596,800	
	Rock footings	"	2 40	103,220	247,730	
	Rock trench	"	4 10	320	1,310	
	Gates, towers, hoists, etc				654,980	
	Unwatering				3,700,000	
						11,480,590
48. Sewer for paper mill at Mille Roches	See Table No. 4—Item No. 47 (*b*)					171,740
49. 14 ft. Lck, entrance piers and weir at Mille Roches	Concrete	Cu. yd.	12 00	11,770	141,240	
	Concrete	"	10 00	110,350	1,103,500	
	Foundation contingency				14,120	
	Cribwork	Cu. yd.	5 00	3,160	15,800	
	Excavation—Earth	"	0 90	219,510	197,560	
	Rock footings	"	2 40	2,750	6,600	
	Rock trench	"	4 10	1,100	4,510	
	Lock gates, valves, operating machinery, etc				76,000	
	Sluice gates, hoists, etc				30,800	
						1,590,130
50. Railroad changes	Canadian side C. N. Rly. at Moulinette—Raising line	mile	100,000 00	1·0	100,000	
						100,000
51. Clearing pool		Ace	100 00	560	56,000	
						56,000
52. Highway changes	United States Shore—Roads				60,000	
	Canadian Shore—Roads				485,000	
						545,000
53. Property Damages—U.S. side	Improvements				188,000	
	Flowage—U.S. shore				44,160	
	U.S. shore				84,000	
	Long Sault Island				117,480	
	Barnhart Island				219,120	
	Other Islands				52,000	

	Severance				2,750	
	Seepage				20,000	727,510
54. Property damages—Canadian Shore	Improvements				1,109,210	
	Flowage—Canadian shore				260,000	
	Orchards				12,500	
	Sheek island				39,600	
	Existing power development				149,160	1,570,470
						26,332,760
55. Engineering and contingencies	12½ per cent					3,291,240
56. Total						29,624,000
LOWER POOL—WORKS PRIMARILY FOR POWER—SUBSTRUCTURES, HEAD AND TAIL-RACE EXCAVATION—						
57. Head and tail-race excavation—						
(a) At Upper and Lower Sheek Island dams	Excavation—Earth	Cu. yd.	0 90	727,340	654,610	
	Earth overdepth	"	0 90	46,710	42,040	
	Masonry	"	4 25	530	2,260	698,910
(b) Between Sheek and Barnhart Island	Excavation—Earth	Cu. yd.	0 65	1,446,000	939,900	939,900
(c) Above power house	Excavation—Earth	Cu. yd.	0 65	975,590	634,130	634,130
(d) Tail-race	See Table No 4—Item No. 57 (b)					7,118,040
58. Spillway North of Power House	Concrete	Cu. yd.	12 00	74,670	896,040	
	Concrete	"	10 00	86,770	867,700	
	Foundation contingency				89,610	
	Excavation—Earth	Cu. yd.	0 65	72,700	47,260	
	Rock footings	"	2 40	15,910	38,190	
	Rock trench	"	4 10	2,100	8,610	1,947,410
Brought forward						11,338,390
59. Ice sluices at south end of power house	Concrete	Cu. yd.	12 00	81,380	976,560	
	Concrete	"	10 00	42,650	426,500	
	Foundation contingency				97,660	
	Excavation—Earth	Cu. yd.	0 65	740,500	481,320	
	Rock footings	"	2 40	12,750	30,600	
	Rock trench	"	4 10	880	3,610	
	Gates, towers, hoists, etc				74,000	2,090,250
60. Power house substructure, etc	Concrete	Cu. yd.	15 00	840,700	12,610,500	
	Gates, racks, etc				3,309,880	
	Unwatering				1,905,230	17,825,610
61. Railway Spur to power house	See Table No. 4—Item No. 61					318,000
Carried forward						31,572,250

TABLE No. 5.—INTERNATIONAL RAPIDS SECTION—CRYSLER ISLAND—TWO-STAGE DEVELOPMENT—217—*Concluded*

See Plates Nos. 34–38

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						31,572,250
LOWER POOL—WORKS PRIMARILY FOR POWER—SUBSTRUCTURES, HEAD AND TAIL- RACE EXCAVATION—*Con.*						
62. Engineering and contingencies	12½ per cent					3,946,750
63 Total						35,519,000
LOWER POOL—WORKS PRIMARILY FOR POWER—MACHINERY AND SUPERSTRUCTURE—						
64. Barnhart Island power house	Generators and turbines—36–44, 500 H.P. units				26,058,240	
	Switching				7,745,760	
	Cranes and service units				550,880	
	Superstructure				4,239,000	38,593,880
65. Engineering and contingencies	12½ per cent					4,824,120
66. Total						43,418,000

SUMMARY

UPPER POOL—Works solely for navigation	Item No. 4	8,732,000	
Works common to navigation and power	" 18	69,986,000	
Works primarily for power—			
Substructures, head and tail-race excavation	" 25	25,698,000	
Machinery and superstructure	" 28	30,760,000	135,176,000
LOWER POOL—Works solely for navigation	Item No. 42	25,618,000	
Works common to navigation and power	" 56	29,624,000	
Works primarily for power—			
Substructure, head and tail-race excavation	" 63	35,519,000	
Machinery and superstructure	" 66	43,418,000	134,179,000
Total			269,355,000

Additional cost if dam is placed between Adams Island and North Shore at Galop Rapids $2,654,000

TABLE No. 6—INTERNATIONAL RAPIDS SECTION—SINGLE STAGE DEVELOPMENT—238

See Plates Nos. 39—43

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
WORKS SOLELY FOR NAVIGATION—						
1. Channel excavation—						
(a) Approach channels—Lotus Island lock	Excavation—Earth	Cu. yd.	0 65	725,000	471,250	
	Dry rock	"	1 60	170,000	272,000	
	Dredging	"	0 90	1,196,910	1,077,220	
	Over depth	"	0 90	51,850	46,670	1,867,140
(b) Above Long Sault Island to Robinson Bay lock	Excavation—Dry earth	Cu. yd.	0 65	2,259,520	1,468,690	
	Paving	"	11 00	10,020	110,220	1,578,910
(c) Robinson Bay lock to below Cornwall Island	See Table No. 4—Items No. 28 (c) to 28 (f)					2,527,830
2. Drainage ditch	Excavation—Earth	Cu. yd.	0 65	10,200	6,630	6,630
3. Dikes—						
(a) Above Robinson Bay lock	Earth fill	Cu. yd.	0 42	338,180	142,040	
	Earth fill	"	0 60	1,644,510	986,710	
	Rock fill	"	1 00	155,400	155,400	
	Stripping	"	0 65	232,960	151,620	
	Trimming	Sq. yd.	25	173,740	43,440	
	Paving—Concrete	Cu. yd.	11 00	14,300	157,300	1,636,510
(b) Robinson Bay lock to Grass River	See Table No. 4—Item No. 30 (b)					795,000
(c) Rock fill—Guide dike below Grass River lock	See Table No. 4—Item No. 30 (c)					126,000
4. Lotus Island lock and entrance piers	Concrete	Cu. yd.	10 00	171,070	1,710,700	
	Excavation—Dry rock	"	1 60	54,650	87,440	
	Rock trench	"	4 10	2,100	8,610	
	Earth	"	0 65	363,770	236,450	
	Close drilling	sq. ft.	0 45	37,570	16,910	
	Gates and operating machinery				634,500	
	Valves and operating machinery				100,000	
	Fenders, capstans, lighting equipment, etc				181,700	
	Emergency gate				175,000	
	Operating buildings, etc				25,000	3,176,310
5. Guard gate and supply weir above Robinson Bay lock	Concrete	Cu. yd.	12 00	4,520	54,240	
	Concrete	"	10 00	34,080	340,800	
	Foundation contingency				5,400	
	Cribwork	Cu. yd.	5 00	38,390	191,950	
	Excavation—Earth	"	0 65	42,960	27,920	
	Trench	"	3 10	3,370	10,450	
	Sheeting and bracing	M. ft.b.m.	10 00	61	6,710	
Carried fordwar						11,714,330

TABLE No. 6—INTERNATIONAL RAPIDS SECTION—SINGLE STAGE DEVELOPMENT—224—*Continued*

See Plates Nos. 39-43.

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						11,714,330
WORKS SOLELY FOR NAVIGATION—*Con.*						
5. Guard gate and supply weir above Robinson Bay lock	Lock gates, operating machinery, etc				121,530	
	Sluice gates, hoists, etc				33,800	
						792,800
6. Robinson Bay lock—Entrance piers and weir	Concrete	Cu. yd.	10 00	281,650	2,816,500	
	Concrete	"	15 00	108,660	1,629,900	
	Cribwork	"	5 00	79,320	396,600	
	Excavation—Earth	"	0 65	881,020	572,660	
	Lock gates and operating machinery				684,000	
	Lock valves and operating machinery				100,000	
	Emergency gate				175,000	
	Fenders, capstans, lighting equipment, etc				206,700	
	Sluice gates, hoists, etc				52,690	
						6,634,050
7. Regulating weir at Robinson Bay	See Table No. 4—Item No. 33					698,000
8. Grass River lock and entrance piers	" 4— " 34					5,886,170
9. N.Y.C. Rly. diversion and bridges	" 4— " 35					1,308,000
10. Canal lighting and office	" 4— " 36					16,000
11. Clearing pool	" 4— " 37					15,000
12. Roads	" 4— " 38					117,690
13. Property damages	" 4— " 39					596,930
						27,778,970
14. Engineering and contingencies	12½%					3,472,030
15. Total						31,251,000
WORKS COMMON TO NAVIGATION AND POWER—						
16. Channel excavation—						
(*a*) Chimney Point to below Point Three Points	See Table No. 4—Items No. 5 (*a*) to 5 (*o*) inclusive					30,986,730
(*b*) Point Three Points to below Canada Island	See Table No. 5—Items No. 5 (*b*) to 5 (*f*) inclusive					6,131,720
(*c*) North side of Cornwall Island	See Table No. 4—Item No. 43 (*b*)					1,027,650
(*d*) South side of Cornwall Island	" 4— " 43 (*c*)					2,922,180
17. Dam at head of channel through Galop Island	" 4— " 7					1,598,710
18. Dams and banks in South Galop	Concrete	Cu. yd.	12 00	73,030	876,360	
	Concrete	"	10 00	8,500	85,000	

	Foundation contingency				87,640	
	Excavation—Earth	Cu. yd.	0 65	66,270	43,080	
	Rock footings	"	2 40	19,340	46,420	
	Rock trench	"	4 10	600	2,460	
	Gates, towers, hoists, bridges, etc.				1,548,170	
	Banks—Earth fill	Cu. yd.	0 60	114,760	68,860	
	Rock fill	"	0 60	99,540	59,720	
	Stripping	"	0 65	22,620	14,700	
						2,832,410
19. Dikes—						
(a) Canadian shore—West of Aultsville to Dickenson's Landing	Earth fill	Cu. yd.	0 65	1,210,510	786,830	
	Rock fill	"	1 00	466,350	466,350	
	Stripping	"	0 65	276,700	179,860	
						1,433,040
(b) East and west of 14-ft. lock at head of Sheek Island	Earth fill	Cu. yd.	0 65	321,460	208,950	
	Earth fill	"	0 90	379,340	341,410	
	Rock fill	"	1 00	242,080	242,080	
	Stripping	"	0 65	107,220	69,700	
						862,140
(c) Skeek Island to power house	Earth fill	Cu. yd.	0 90	4,850,000	4,365,000	
	Rock fill	"	0 60	1,183,920	710,350	
	Stripping	"	0 65	295,130	191,830	
						5,267,180
(d) United States shore—Wilson Hill to Louisville Landing	Earth fill	Cu. yd.	0 90	183,400	165,060	
	Rock fill	"	1 00	77,610	77,610	
	Stripping	"	0 65	48,470	31,510	
						274,180
(e) West and east of Massena Canal	Earth fill	Cu. yd.	0 90	773,160	695,840	
	Rock fill	"	1 00	275,450	275,450	
	Stripping	"	0 65	128,570	93,570	
						1,064,860
(f) Between Massena Canal and Navigation Canal	Earth fill	Cu. yd.	0 65	180,380	117,250	
	Rock fill	"	1 00	67,020	67,020	
	Stripping	"	0 65	35,610	23,150	
						207,420
(g) East and west of Long Sault dam	Earth fill	Cu. yd.	0 90	161,170	145,050	
	Rock fill	"	1 00	37,380	37,380	
	Stripping	"	0 65	19,050	12.380	
						194,810
(h) On Barnhart Island	Earth fill	Cu. yd.	0 90	648,850	583,960	
	Rock fill	"	1 00	222,180	222,180	
	Stripping	"	0 65	103 580	67,330	
						873,470
20. Supply channel and Weir at Massena Canal	Concrete	Cu. yd.	12 00	25,890	310,680	
	Concrete	"	10 00	55,660	556,600	
	Foundation contingency				31,070	
	Excavation—Rock footings	Cu. yd.	2 40	5,210	12,510	
	Rock trench	"	4 10	590	2,420	
	Earth	"	0 65	961,910	625,240	
Carried forward						55,676,500

TABLE No. 6—INTERNATIONAL RAPIDS SECTION—SINGLE STAGE DEVELOPMENT—238—*Continued*

See Plates Nos. 34-39

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						55,676,500
WORKS SOLELY FOR NAVIGATION—*Con.*						
20. Supply channel and weir at Massena Canal	Excavation—Dredging	Cu. yd.	0 90	43,000	38,000	
	Over depth	"	0 90	3,000	2,700	
	Concrete paving	"	11 00	6,550	72,050	
	Gates, bridges, hoists, etc.				75,700	
						1,727,670
21. Diversion cut through Long Sault Island	See Table No. 4—Item No. 45					2,055,370
22. Main Long Sault Dam	Concrete	Cu. yd.	12 00	716,140	8,593,680	
	Concrete	"	10 00	65,010	650,100	
	Foundation contingency				859,370	
	Excavation—Earth	Cu. yd.	0 65	1,327,470	862,860	
	Rock footings	"	2 40	120,670	289,610	
	Rock trench	"	4 10	470	1,930	
	Gates, towers, hoists, etc.				646,060	
	Unwatering				3,700,000	
						15,603,610
23. Drainage—Ditches, etc.—E. Williamsburg to Bergen Lake	Excavation—Earth	Cu. yd.	0 65	2,133,470	1,386,760	
	Bridges				129,500	
	Concrete drops				58,000	
						1,574,260
24. 14 H. Lock, entrance piers and Weir at head of Sheek Island	Concrete	Cu. yd.	12 00	11,100	133,200	
	Concrete	"	10 00	108,750	1,087,500	
	Foundation Contingency				13,320	
	Cribwork	Cu. yd.	5 00	4,500	22,500	
	Excavation—Earth	"	0 90	41,970	37,780	
	Earth trench	"	3 10	4,250	13,180	
	Rock trench	"	4 10	180	740	
	Sheeting and bracing	M.B.M.	110 00	51·2	5,630	
	Lock gates, valves, operating machinery, etc.				84,110	
	Sluice gates, hoists, etc.				30,800	
						1,428,760
25. Railroad changes	C.N.R. at Iroquois—to be raised	Mile	100,000 00	1·5	150,000	
	Bridges for above				30,000	
	C.N.R. east of Morrisburg	Mile	100,000 00	3·3	330,000	
	Norwood and St. L. Railway	"	35,000 00	2·6	91,000	
	Bridges for above				29,000	
						630,000
26. Clearing Pool	Above Morrisburg	Acre	100 00	510	51,000	
	Below Morrisburg	"	100 00	3,740	374,000	
						425,000

27. Highway changes—						
(a) Above Morrisburg	Canadian shore	Mile	50,000 00	8	400,000	
	Bridges				20,000	
	U.S. Shore				37,000	457,000
(b) Below Morrisburg	Canadian shore	Mile	50,000 00	18·2	910,000	
	Bridges				7,000	
	U.S. shore-Concrete	Mile	60,000 00	7·2	432,000	
	Earth	"	5,000 00	1·5	7,500	
	Bridges				73,000	1,429,500
28. Property damages—U.S. side.—						
(a) Above Morrisburg	Improvements				64,000	
	Town property required				411,000	
	Farm lands				128,000	
	Farm lands in severance				3,000	606,000
(b) Below Morrisburg	Improvements				486,000	
	Flowage				182,530	
	Flowage				661,000	
	Severance				10,200	
	Seepage				25,000	1,364,730
29. Property damage—Islands—						
(a) Above Morrisburg	Flowage				170,000	
	Improvements				87,000	257,000
(b) Below Morrisburg	Long Sault Island—Flowage				265,320	
	Barnhart Island—Flowage				219,120	
	Sheek Island—Flowage				52,800	
	Sheek Island—Seepage				25,000	
	Other Islands—improvements				256,000	
	Flowage				201,500	1,019,740
30. Property Damages—Canadian shore—						
(a) Above Morrisburg	Improvements				593,860	
	Flowage				235,600	
	Orchards				30,500	
	Existing power development				124,110	984,070
(b) Below Morrisburg	Improvements				2,274,670	
	Flowage				734,000	
	Orchards				43,000	
	Existing power developments				149,160	3,200,830
31. Protection to Towns—						
(a) Iroquois	Bank—Earth fill	Cu. yd.	0 90	772,030	701,130	
	Rock fill	"	1 00	229,120	229,120	
	Stripping	"	0 65	207,610	134,950	
	Ditches—Excavation	"	0 65	76,600	49,790	
	Highway and R. R. Bridges				41,000	
	Sewers and pumping				27,000	1,182,990
Carried forward	—					89,623,030

TABLE No. 6.—INTERNATIONAL RAPIDS SECTION—SINGLE STAGE DEVELOPMENT—238—*Continued*

See Plates Nos. 34–39

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						89,623,030
WORKS SOLELY FOR NAVIGATION—*Con.*						
31. Protection to towns—*Con.*						
(*b*) Morrisburg	Bank—Earth fill	Cu. yd.	0 90	255,330	229,800	
	Rock fill	"	1 20	105,550	105,550	
	Stripping	"	0 65	56,010	30,410	
	Drainage Ditch—Excavation—Earth	"	0 65	8,000	5,200	
	Sewers and pumping				55,000	
						431,960
(*c*) Farrans Point	Pumping plant, etc				29,000	29,000
(*d*) Aultsville	Pumping plant, etc				36,000	36,000
						90,119,990
32. Engineering and contingencies	12½ per cent					11,265,010
33. Total						101,385,000
WORKS PRIMARILY FOR POWER—SUBSTRUCTURES, HEAD AND TAIL-RACE EXCAVATION, ETC.						
34. Head and tail-race excavation—						
(*a*) Between Sheek and Barnhart Island	Excavation—Dry earth	Cu. yd.	0 65	6,916,800	4,495,920	
	Dredging	"	0 90	424,300	381,870	
	Overdepth	"	0 90	72,300	65,070	4,942,860
(*b*) Tail-race	See Table No. 4—Item No. 57 (*b*)					7,118,040
35. Spillway north of power house	Concrete	Cu. yd.	12 00	86,860	1,042,320	
	Concrete	"	10 00	118,350	1,183,500	
	Foundation contingency				104,230	
	Excavation—Earth	Cu. yd.	0 65	28,750	18,690	
	Rock footings	"	2 40	14,550	34,920	
	Rock trench	"	4 10	2,250	9,220	
						2,392,880
36. Ice sluices at south end of power house	Concrete	Cu. yd.	12 00	119,470	1,433,640	
	Concrete	"	10 00	98,570	985,700	
	Foundation contingency				143,370	
	Excavation—Earth	Cu. yd.	0 65	1,030,660	669,930	
	Rock footings	"	2 40	15,350	36,840	
	Rock trench	"	4 10	700	2,870	
	Gates, hoists, towers, etc				74,000	
						3,346,350

37. Power house substructure, etc.	Concrete	Cu. yd.	15 00	1,224,640	18,369,600	
	Gate, racks, etc.				3,200,570	
	Unwatering				1,905,230	
						23,475,400
38. Railway spur to power house	See Table No. 4—Item No. 61					318,000
						41,593,530
39. Engineering and contingencies	12½ per cent					5,448,470
40. Total						47,042,000
WORKS PRIMARILY FOR POWER—MACHINERY AND SUPERSTRUCTURE—						
41. Barnhart Island power house	Generators and turbines—44–50, 600 H.P. units				29,660,400	
	Switching				8,709,800	
	Cranes and service units				498,680	
	Superstructure				4,626,750	
						43,495,630
42. Engineering and contingencies	12½ per cent					5,436,370
43. Total						$ 48,932,000

SUMMARY

Works solely for navigation	Item No. 15		$ 31,251,000
Works common to navigation and power	" 33		101,385,000
Works primarily for power—			
Substructures, head and tail-race excavation, etc	" 40		47,042,000
Machinery and superstructure	" 43		48,932,000
Total			$ 228,610,000

TABLE 7.—IMPROVEMENT OF INTERNATIONAL RAPIDS SECTION FOR NAVIGATION ALONE (CHANNEL 25-FEET DEEP)

Item	Quantity	Unit	Unite price	Amount	Subtotals
			$ cts.	$	$
1. Channel excavation, Chimney Point:					
Dredging	513,000	Cu. yd.	0 80	250,000	
Dredging over depth	41,000	"	0 80	33,000	
Dredging rock	185,000	"	4 25	786,000	
Dredging, rock, over depth	38,000	"	4 25	162,000	
					1,231,000
2. Approach channel to upper lock—					
Excavation, earth	149,000	"	0 65	97,000	
Excavation, rock	179,000	"	1 75	313,000	
Dredging	268,000	"	0 80	214,000	
Dredging over depth	23,000	"	0 80	18,000	
Riprap dike	260,000	"	1 00	260,000	
					902,000
3. Guard lock at Galop (Lock 10):—					
Excavation, earth	505,000	"	0 65	328,000	
Excavation, rock	714,300	"	1 75	305,000	
Back fill	120,000	"	0 40	48,000	
Concrete	141,700	"	10 00	1,417,000	
Gates				524,000	
Operating machinery				200,000	
Emergency dam				175,000	
Approach walls—					
Concrete	27,700	"	10 00	277,000	
Cribbing	56,900	"	8 00	455,000	
Office and dwellings				40,000	
					3,769,000
4. Sluiceway at guard lock—					
Excavation, earth	400,000	"	0 65	260,000	
Excavation, rock	900	"	3 50	3,000	
Back fill	8,000	"	0 40	3,000	
Concrete	3,400	"	10 00	34,000	
Gates and operating machinery				4,000	
					304,000
5. Canal, Lock 10 to Lock 9—					
Excavation, earth	17,893,000	"	0 65	11,630,000	
Excavation, rock	1,407,000	"	1 75	2,462,000	
Dikes, rock fill	402,800	"	2 00	806 000	
Dikes, earth fill	1,734,000	"	0 75	1,301,000	
Concrete, bank protection	90,000	Lin. ft.	9 00	810,000	
Lighting	12·2	Miles	2,000 00	24,000	
					17,033,000
6. Lock at Ogden Island (Lock 9)—					
Unwatering				390,000	
Excavation, earth	118,000	Cu. yd.	0 65	77,000	
Excavation, rock	153,000	"	1 75	268,000	
Back fill	170,000	"	0 40	68,000	
Concrete	131,000	"	10 00	1,310,000	
Gates				542,000	
Operating machinery				300,000	
Approach walls, concrete	22,500	"	10 00	225,000	
Approach walls, cribbing	43,300	"	8 00	346,000	
					3,526,000
7. Weir and abutment at Lock 8—					
Excavation, earth	33,000	Cu. yd.	0 65	22,000	
Excavation trench	1,000	"	5 00	5,000	
Excavation, rock	8,000	"	3 50	28,000	
Back fill	8,000	"	0 40	3,000	
Concrete	27,400	"	10 00	274,000	
Stop logs and bridge				17,000	
					349,000
8. Navigation channel, Lock 9 to Long Sault Island—					
(*a*) Lock 9 to Murphy Island—					
Excavation, earth	980,000	"	0 65	637,000	
Excavation, rock, dry	20,000	"	1 75	35,000	
Dredging	956,000	"	0 90	860,000	
Dredging	86,000	"	0 90	77,000	
Dredging, rock	187,000	"	4 25	795,000	
Dredging, rock, over depth	34,000	"	4 25	145,000	
					2,549,000

TABLE 7.—IMPROVEMENT OF INTERNATIONAL RAPIDS SECTION FOR NAVIGATION ALONE (CHANNELS 25-FEET DEEP)—*Continued*

Item	Quantity	Unit	Unit price	Amount	Subtotals
			$ cts.	$	
8. Navigation channel, Lock 9 to Long Sault Island—*Con.*					
(*b*) Murphy Island to Weavers Point					
Dredging	369,000	Cu. yd.	0 90	332,000	
Dredging over depth	57,000	"	0 90	51,000	
					383,000
(*c*) Weavers Point to entrance Long Sault Canal—					
Dredging	378,000	"	0 90	340,000	
Dredging, over depth	28,000	"	0 90	25,000	
					365,000
					3,297,000
9. Channel, Long Sault Island to Lock 8					
Excavation, earth	3,773,000	"	0 65	2,452,000	
Concrete bank protection	13,000	Lin. ft.	9 00	117,000	
Lighting	11	Miles	2,000 00	2,000	
					2,571,000
10. Lock 8—					
Excavation earth	1,070,000	"	0 65	696,000	
Excavation, rock	15,650	"	3 50	55,000	
Back fill	512,000	"	0 40	208,000	
Concrete	278,000	"	10 00	2,780,000	
Gates				600,000	
Operating machinery				300,000	
Emergency dam				175,000	
Approach walls, concrete	52,500	"	12 00	630,000	
Approach walls, piling	187,000	Lin. ft.	0 85	159,000	
Office and dwellings				40,000	
					5,643,000
11. Canal prism, Lock 8 to Grass River lock—					
Estimate III, item 2 (*e*)				4,176,000	
					4,176,000
12. Dike at Robinson Bay—					
Estimate III, item 2 (*d*)				85,000	
					85,000
13. Lock 7, Grass River—					
Estimate III, item 2 (*f*)				6,067,000	
					6,067,000
14. Approach channel, Grass River lock to river—					
Estimate I, item 2 (*e*)				227,000	
					227,000
15. Dike at Grass River lock—					
Estimate I, item 2 (*f*)				307,000	
					307,000
16. Waste weir at Grass River lock—					
Estimate I, item 2 (*g*)				757,000	
					757,000
17. Drainage ditch, north of Grass River lock—					
Estimate I, item 2 (*h*)				2,000	
					2,000
18. Diversion dike and flood channel at mouth of Grass River—					
Estimate I, item 2 (*i*)				307,000	
					307,000
19. Diversion of Ottawa Branch, New York Central Railroads—					
Estimate I, item 2 (*j*)				1,308,000	
					1,308,00
20. Channel excavation, Lake St. Francis to mouth of Grass River—					
Dreding	1,990,000	Cu. yd.	0 60	1,592,000	
Dredging over depth	25,.000	"	0 80	200,000	
					1,792,000

TABLE 7.—IMPROVEMENT OF INTERNATIONAL RAPIDS SECTION FOR NAVIGATION ALONE (CHANNEL 25-FEET DEEP)—*Continued*

Item	Quantity	Unit	Unit price	Amount	Subtotals
			$ cts.	$	$
21. Dam across main river channel at head of Long Sault Rapids—					
Dam—					
Excavation, earth	89,000	Cu. yd.	0 80	71,000	
Excavation, rock	54,000	"	3 50	190,000	
Concrete	144,000	"	12 00	1,728,000	
Foundation contingencies	....	10%	....	173,000	
Gates, stop logs, bridge, cranes	....	....	....	387,000	
Unwatering	....	....	....	3,000,000	
Abutments—					
Excavation, earth	50,000	Cu. yd.	0 65	33,000	
Excavation, trench	4,000	"	5 00	20,000	
Excavation, rock	2,400	"	3 50	8,000	
Back fill	34,000	"	0 40	14,000	
Concrete	22,100	"	10 00	221,000	
					5,845,000
22. Diversion cut and control works across long Sault Islands—					
Cut—					
Excavation, earth	2,340,000	"	0 65	1,521,000	
Excavation, rock	125,000	"	1 75	219,000	
Excavation, dredging	70,7000	"	0 70	495,000	
Concrete lining	32,000	"	12 00	384,000	
Control works—					
Excavation, rock	4,400	"	3 50	15,000	
Concrete	32,300	"	12 00	368,000	
Foundation contingencies	....	10%	....	39,000	
Gates stop logs, bridge, cranes	....	....	....	224,000	
Abutments—					
Excavation, earth	45,000	"	0 65	29,000	
Excavation, trench	3,100	"	5 00	16,000	
Excavation, rock	4,600	"	3 50	16,000	
Back fill	32,000	"	0 40	13,000	
Concrete	20,500	"	10 00	205,000	
					3,564,000
3. Dam across South Sault—					
Dam—					
Excavation, earth	2,600	Cu. yd.	0 80	2,000	
Excavation rock	13,900	"	3 50	49,000	
Concrete	43,000	"	12 00	516,000	
Foundation contingencies	....	10%	....	52,000	
Gates, stop logs, bridge, cranes	....	....	....	112,000	
Unwatering	....	....	....	500,000	
Abutments—					
Excavation, earth	66,400	Cu. yd.	0 65	43,000	
Excavation, trench	5,100	"	5 00	26,000	
Excavation, rock	2,800	"	3 50	10,000	
Back fill	30,000	"	0 40	12,000	
Concrete	44,100	"	10 00	441,000	
					1,763,000
24. Control works, head of Massena Canal—					
Excavation, earth	922,000	Cu. yd.	0 65	599,000	
Excavation, rock	3,700	"	3 50	13,000	
Dredging	96,000	"	0 90	86,000	
Concrete	23,500	"	12 00	282,000	
Foundation contingencies	....	10%	....	28,000	
Paving	7,800	Cu. yd.	12 00	94,000	
Gate house	332,000	Cu. ft.	0 25	83,000	
Gates	....	....	....	60,000	
Operating machinery and stop logs	....	....	....	37,000	
					1,282,000
25. Dikes—					
(a) Massena Canal, inclusive, to dam—					
Earth fill	170,000	Cu. yd	0 75	128,000	
Rock fill	50,600	"	2 00	101,000	
Riprap slope protection	2,100	"	3 00	6,000	
(b) At Hoople Creek—					
Earth fill	65,000	"	0 75	49,000	
Riprap slope protection	2,000	"	3 00	6,000	
					290,000

TABLE 7.—IMPROTEMFNT OF INTERNATIONAL RAPIDS SECTION FOR NAVIGATION ALONE CHANNEL 25-FEET DEEP—*Concluded*

Item	Quantity	Unit	Unit price	Amount	Sub-totals
26. Flowage and damages—					
Canal right of way—					
Galop to Waddington				646,000	
Canadian shore—					
Flowage				150,000	
Improvements				874,000	
United States shore, to Massena Canal—					
Flowage and severance				158,000	
Improvements				371,000	
Islands—					
Flowage				117,000	
Improvements				139,000	
Canal right of way, etc., Long Sault Island to Grass River—					
Lands				581,000	
Severance				270,000	
					3,306,000
27. Highway relocation—					
Canadian shore—					
Roads, concrete	6·8	Miles	40,000 00	272,000	
Bridges				31,000	
United States shore, to Massena Canal—					
Roads, concrete	2	Miles	40,000 00	80,000	
Roads, earth	0·5		6,000 00	3,000	
Bridges				61,000	
United States shore, below Massena Canal—					
Roads				118,000	
					565,000
28. Clearing pools	550	Acres	100 00	55,000	
					55,000
					70,323,000
Engineering, administration and contingencies		12½%			8,790,000
Total					79,113,000

TABLE 8.—LAKE ST. FRANCIS SECTION—RECOMMENDED PROJECT

See Plates Nos. 46–48

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
(A) DEPTH OF NAVIGATION CHANNEL—25 FT.—						
1. Glengarry Point to Hamilton Island	Excavation—Earth	Cu. yd.	0 55	762,940	419,620	
	Over depth	"	0 55	86,460	47,550	
						467,170
2. Hamilton Island to Squaw Island	Excavation—Earth	Cu. yd.	0 55	200,300	110,170	
	Earth, over depth	"	0 55	73,350	40,340	
						150,510
3. Lancaster Bar	Excavation—Earth	Cu. yd.	0 55	398,700	219,290	
	Earth, over depth	"	0 55	54,170	29,790	
						249,080
4. East of Hay Point	Excavation—Earth	Cu. yd.	0 55	6,210	3,420	
	Earth, over depth	"	0 55	2,410	1,320	
						4,740
						871,500
5. Engineering and contingencies	12½%					108,500
Total						980,000
(B) DECREASE IN COST FOR 23-FT. DEPTH—						
Decrease	Excavation—Earth	Cu. yd.	0 55	418,110	229,960	
	Earth, over depth	"	0 55	53,220	29,270	
						259,230
Engineering and contingencies	12½%					32,770
Total decrease						292,000
(C) INCREASE IN COST FOR 27-FT. DEPTH—						
Increase	Excavation—Earth	Cu. yd.	0 55	506,130	278,370	
	Earth, over depth	"	0 55	60,050	33,030	
						311,400
Engineering and contingencies	12½%					38,600
Total increase						350,000
(D) COST TO DEEPEN FROM 25 FT. TO 30 FT. DEPTH	Excavation—Earth	Cu. yd.	0 55	1,350,200	742,610	
	Earth, over depth	"	0 55	346,710	190,690	
						933,300
Engineering and contingencies	12½%					116,700
Total cost to deepen						1,050,000

TABLE 9.—SOULANGES SECTION—RECOMMENDED PROJECT—NAVIGATION COMBINED WITH THE DEVELOPMENT OF POWER (THREE STAGE DEVELOPMENT)

See Plates Nos. 49–51

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
WORKS SOLELY FOR NAVIGATION—						
1. Channel excavation—						
(a) Deep water in Lake St. Francis to below Pointe au Diable	Excavation—Earth	Cu. yd.	0 65	3,775,050	3,453,780	
	Earth, over depth	"	0 65	187,890	122,130	
	Dry rock	"	1 60	903,300	1,445,280	
	Wet rock	"	4 25	45,480	193,290	
	Wet rock, over depth	"	4 25	16,800	71,400	
	Cribwork	"	1 60	45,210	72,340	
	Paving—Riprap	"	2 70	11,900	32,130	4,390,350
(b) At Leonard Island	Excavation—Earth	Cu. yd.	0 65	133,910	87,040	
	Dry rock	"	1 60	196,950	315,120	
	Wet rock	"	4 25	30,360	129,030	
	Wet rock, over depth	"	4 25	740	3,150	
	Unwatering				238,100	772,440
(c) Canal, P.L.H. & P. Co. head-race to Chamberry Gully lock	Excavation—Earth	Cu. yd.	0 55	1,183,890	651,140	651,140
(d) Chamberry Gully lock to Cascades lock	Excavation—Earth	Cu. yd.	0 55	2,365,400	1,300,970	
	Paving—Concrete	"	11 00	5,250	57,750	1,358,720
(e) Below Cascades lock	Excavation—Earth	Cu. yd.	0 65	1,036,600	673,790	
	Earth, over depth	"	0 65	105,000	68,250	742,040
2. Dikes—						
(a) Breakwaters, Lake St. Francis	Excavation—Earth	Cu. yd.	0 65	106,780	69,410	
	Wet rock	"	4 25	5,330	22,650	
	Rock fill	"	1 80	415,430	747,770	
	Concrete	"	9 00	6,470	58,230	
	Cribwork	"	5 00	86,280	431,400	1,329,460
(b) Above Coteau du Lac	Earth fill	Cu. yd.	0 42	468,660	196,840	
	Rock fill	"	0 60	191,820	115,090	
	Stripping	"	0 65	103,590	67,340	379,270
(c) Cedars Village to Chamberry Gully lock	Earth fill	Cu. yd.	0 42	1,266,320	531,850	
	Earth fill	"	0 60	1,375,550	825,330	
Carried forward						9,623,420

TABLE 9.—SOULANGES SECTION—RECOMMENDED PROJECT—NAVIGATION COMBINED WITH THE DEVELOPMENT OF POWER (THREE STAGE DEVELOPMENT)—*Continued*

See Plates Nos. 49–51.

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						9,623,420
WORKS SOLELY FOR NAVIGATION—*Con.*						
2. Dikes—*Con.*						
(*c*) Cedars Village to Chamberry Gully lock—*Con.*	Rock fill	Cu. yd.	0 80	38,160	30,530	
	Rock fill	"	1 00	110,820	110,820	
	Stripping	"	0 65	368,230	239,350	
	Trimming	Sq. yd.	0 25	110,660	27,670	
	Sodding	"	0 45	11,500	5,180	
	Paving—Concrete	Cu. yd.	11 00	8,150	89,650	1,860,380
(*d*) Chamberry Gully lock to Cascades lock	Earth fill	Cu. yd.	0 42	52,580	22,090	
	Stripping	"	0 65	6,980	4,540	
	Trimming	Sq. yd.	0 25	7,650	1,920	28,550
3. Coteau du Lac guard lock and Entrance piers	Concrete	Cu. yd.	9 00	129,160	1,162,440	
	Excavation—Earth	"	0 65	8,630	5,610	
	Rock	"	1 60	169,120	270,590	
	Cribwork	"	5 00	35,000	175,000	
	Close drilling	Sq. ft.	0 45	99,900	44,960	
	Lock gates and operating machinery				591,000	
	Lock valves and operating machinery				100,000	
	Emergency gate				175,000	
	Fenders, capstans, lighting equipment, etc				206,700	
	Unwatering				72,500	2,803,800
4. Guard gate, Entrance piers and weir	Concrete	Cu. yd.	11 00	12,320	135,520	
	Concrete	"	9 00	78,880	709,920	
	Foundation contingency				13,550	
	Cribwork	Cu. yd.	5 00	55,440	277,200	
	Excavation—Earth	"	0 65	398,390	258,950	
	Rock footings	"	2 40	2,860	6,860	
	Rock trench	"	4 10	750	3,080	
	Round bearing piles	Lin. ft.	0 85	87,600	74,460	
	Gates, operating machinery, etc				449,800	1,929,340
5. Chamberry Gully lock, Entrance piers and weir	Concrete	Cu. yd.	11 00	14,850	163,350	
	Concrete	"	9 00	159,970	1,439,730	
	Concrete	"	14 00	120,270	1,683,780	
	Foundation contingency				16,340	
	Cribwork	Cu. yd.	5 00	73,890	369,450	

	Close drilling	Sq. ft.	0 45	48,480	21,820	
	Excavation—Earth, dry	Cu. yd.	0 65	1,559,340	1,013,570	
	Rock, dry	"	1 60	82,200	131,520	
	Rock, footings	"	2 40	3,080	7,390	
	Rock, trench	"	4 10	570	2,340	
	Round bearing piles	Lin ft.	0 85	2,880	2,450	
	Lock gates and operating machinery				785,600	
	Lock valves and operating machinery				100,000	
	Fenders, capstans, lighting equipment, etc				161,700	
	Sluice gates, hoists, etc				22,800	
						5,921,840
6. Cascades Lock, entrance piers and weir	Concrete	Cu. yd.	11 00	7,150	78,650	
	Concrete	"	9 00	252,730	2,274,570	
	Foundation contingency				7,870	
	Cribwork	Cu. yd.	5 00	111,400	557,000	
	Close drilling	S.f.	0 45	43,240	19,460	
	Excavation—Earth	Cu. yd.	0 65	989,870	643,420	
	Dry rock	"	1 60	116,340	186,090	
	Rock footings	"	2 50	2,200	5,280	
	Rock trench	"	4 10	250	1,030	
	Unwatering				128,800	
	Lock gates and operating machinery				675,000	
	Lock valves and operating machinery				100,000	
	Fenders, capstans, lighting equipment, etc				206,700	
	Sluice gates, Hoists, etc				30,800	
						4,914,670
7. Railway bridge for C.N.Ry. at Coteau	Superstructure				283,440	
	Substructure				61,840	
						345,280
8. Highway changes	New roads	Mile	40,000 00	0·6	24,000	
	Bridge				110,000	
						134,000
9. Canal lighting and offices					35,000	
						35,000
10. Property damages above Pointe au Diable	Improvements				405,040	
	Lands				82,000	
						487,040
						28,083,320
11. Engineering and contingencies	12½ per cent					3,510,680
12. Total						31,594,000

TABLE 9.—SOULANGES SECTION—RECOMMENDED PROJECT—NAVIGATION COMBINED WITH THE DEVELOPMENT OF POWER (THREE STAGE DEVELOPMENT)—*Continued*

See Plates Nos. 49—51

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
WORKS COMMON TO NAVIGATION AND POWER—						
13. Channel excavation—						
(*a*) Coteau Rapids above Clarke's Island to below Broad Island.	Excavation—Earth	Cu. yd.	0 65	2,199,160	1,429,460	
	Earth overdepth	"	0 65	56,450	36,700	
	Dry rock	"	1 60	1,301,040	2,081,670	
	Wet rock	"	4 25	330,370	1,404,080	
	Wet rock overdepth	"	4 25	22,200	94,350	5,046,260
(*b*) Round Island Channel	Excavation—Earth	Cu. yd.	0 65	1,706,000	1,109,290	
	Earth overdepth	"	0 65	114,000	74,100	1,183,290
(*c*) Pointe a Biron	Excavation—Earth	Cu. yd.	0 55	670,600	368,830	
	Earth overdepth	"	0 55	49,260	27,100	395,930
(*d*) Cedars to P.L.H. and P. Co. Head-Race	Excavation—Earth	Cu. yd.	0 55	1,895,200	1,042,360	1,042,360
14. Dykes—						
(*a*) Coteau du Lac to Cedars	Earth fill	cu. yd.	0 75	918,520	688,890	
	Rock fill	"	0 80	410,320	328,260	
	Stripping	"	0 65	277,410	180,320	1,197,470
(*b*) Grande Ile	Earth fill	cu. yd.	0 90	410,310	369,280	
	Rock fill	"	0 84	172,240	144,680	
	Stripping	"	0 65	91,640	59,570	573,530
15. Dams at Clark's Island	Concrete	cu. yd.	11 00	27,310	300,410	
	Concrete	"	9 00	6,350	57,150	
	Foundation contingency				30,040	
	Excavation—Earth	cy. yd.	0 65	12,400	8,060	
	Rock footings	"	2 40	12,635	30,320	
	Unwatering				381,800	
	Gates, towers, hoists, etc				218,850	1,026,630
16. Cedars Dam	Concrete	cu. yd.	11 00	516,680	5,683,480	
	Concrete	"	9 00	58,960	530,640	
	Concrete	"	30 00	83,850	2,515,500	
	Foundation contingency				568,350	
	Excavation—Earth	cu. yd.	0 55	1,054,140	579,780	
	Earth trench	"	3 10	3,940	12,210	
	Rock footings	"	2 40	234,160	561,990	
	Rock trench	"	4 10	1,000	4,100	
	Unwatering				4,064,680	
	Gates, towers, hoists, etc				684,300	
						15,205,030

17. Drainage—						
(a) Diversion River Delisle	Excavation—Earth	cu. yd.	0 65	558,500	363,030	
	Bridges				55,000	
						418,030
(b) Ditch. Cedars to P. L. H. and P. Co. Head-Race	Excavation—Earth	cu. yd.	0 65	15,420	10,020	
						10,020
(c) Culverts for Rivers Graisse, Rouge, Delisle, including excavation Soulanges Canal and existing culverts.	Concrete	cu. yd.	11 00	41,250	453,750	
	Excavation—Earth	"	0 65	897,400	583,310	
	Earth overdepth	"	0 65	28,020	18,210	
	Rock	"	1 60	1,180	1,890	
	Round bearing piles	lin. ft.	0 85	50,490	42,920	
	Accessories				3,860	
						1,103,940
18. Highway changes	New roads				308,000	
	Bridges				751,230	
						1,059,230
19. Property damages	Improvements				711,080	
	Lands				449,000	
						1,160,080
20. Railroad relocation. C.N.Ry. at Bellerive	New line	mile	50,000 00	1·7	85,000	
	Bridges				847,600	
						932,600
21. Interruption in operation of P.L.H. and P. Co.		H.P. Yrs.	20 00	12,000 H.P. 2 Yrs.	480,000	
						480,000
						$ 30,834,500
22. Engineering and Contingencies	12½%					3,851,500
23. Total						$ 34,686,000
FIRST STAGE OF POWER DEVELOPMENT—Ile aux Vaches—404,300 installed H.P.						
(A) WORKS PRIMARILY FOR POWER: SUBSTRUCTURES, HEAD, AND TAIL-RACE EXCAVATION—						
24. Power House Substructures, etc., Ile aux Vaches	Concrete	Cu. yd.	14 00	450,870	6,312,180	
	Excavation—Earth	"	0 55	1,459,420	802,680	
	Earth overdepth	"	0 55	33,000	18,150	
	Dry rock	"	1 60	936,000	1,497,600	
	Unwatering				300,000	
	Gates and racks				1,944,940	
						10,875,550
25. Channel through Grande Ile	Excavation—Earth	Cu. yd.	0 65	1,153,960	750,080	750,080
						$ 11,625,630
26. Engineering and contingencies	12½%					1,453,370
27. Total						$ 13,079,000

TABLE 9.—SOULANGES SECTION—RECOMMENDED PROJECT—NAVIGATION COMBINED WITH THE DEVELOPMENT OF POWER (THREE STAGE DEVELOPMENT)—*Continued*

See Plates Nos. 49–51

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
(B) WORKS PRIMARILY FOR POWER: MACHINERY & SUPERSTRUCTURE—						
28. Power house machinery and superstructure	Generators and turbines, 26—15,550 h.p. units				15,901,600	
	Switching				2,683,200	
	Service units and cranes				477,110	
	Superstructure				2,792,460	
						21,854,370
29. Engineering and contingencies	12½%					2,731,630
30. Total						$24,586,000
SECOND STAGE OF POWER DEVELOPMENT:—Power House North of Cascades Point—545,000 installed h.p.						
(A) WORKS PRIMARILY FOR POWER: SUBSTRUCTURES, HEAD AND TAIL-RACE EXCAVATION—						
31. Head-Race, Cedars to power house	Excavation—Earth	Cu. yd.	0 55	15,512,800	8,532,040	8,532,040
32. Tail-race and power house excavation	Excavation—Earth	"	0 55	1,939,700	1,066,840	
	Earth overdepth	"	0 55	107,000	58,850	
	Dry rock	"	1 60	14,500	23,200	
	Wet rock	"	4 25	22,300	94,780	
	Wet rock overdepth	"	4 25	7,800	33,150	
	Unwatering				450,800	
						1,727,620
33. Dykes, above power house	Earth fill	Cu. yd.	0 42	3,536,610	1,485,380	
	Rock fill	"	1 05	185,000	194,250	
	Stripping	"	0 65	372,100	241,870	
						1,921,500
34. Ice sluices and walls at power house	Concrete	Cu. yd.	11 00	33,320	366,520	
	Concrete	"	9 00	85,190	766,710	
	Foundation contingency				36,650	
	Excavation—Earth	Cu. yd.	0 65	273,900	178,040	
	Earth trench	"	3 10	22,550	69,910	
	Rock footings	"	2 40	6,860	16,460	
	Trench	"	4 10	1,300	5,330	
	Sheeting and bracing	M ft. b.m.	110 00	197	21,670	
	Gates, hoists, etc				90,000	
						1,551,290
35. Power house substructure	Concrete	Cu. yd.	14 00	304,130	4,257,820	
	Gates and racks				1,012,150	
						5,269,970

36. Bridges					442,000	442,000
37. Property damages	Improvements				507,710	
	Lands				184,400	692,110
						20,136,530
38. Engineering and contingencies	12½%					2,517,470
39. Total						22,654,000
(B) WORKS PRIMARILY FOR POWER: MACHINERY AND SUPERSTRUCTURE—						
40. Power house machinery and superstructure	Generators and turbines, 10–54,500 h.p. units				8,789,700	
	Switching				2,220,000	
	Service units and cranes				219,640	
	Superstructure				1,781,570	13,010,910
41. Engineering and contingencies	12½%					1,626,090
42. Total						14,637,000
THIRD STAGE OF POWER DEVELOPMENT:—Dam and Power House at Cascades Rapids—1,030,400 installed h.p.—						
(A) WORKS PRIMARILY FOR POWER: SUBSTRUCTURES, HEAD AND TAIL-RACE EQCAVATION—						
43. Removal of present Cedars power house					480,000	480,000
44. Dam at Cascades Island	Concrete	Cu. yd.	11 00	413,770	4,551,470	
	Concrete	"	9 00	132,560	1,193,040	
	Foundation contingency				455,150	
	Excavation—Earth	Cu. yd.	0 65	22,580	14,680	
	Rock footings	"	2 40	171,850	412,440	
	Unwatering				2,926,940	
	Earth fill	Cu. yd.	0 90	153,350	138,020	
	Rock fill	"	2 00	62,280	124,560	
	Stripping	"	0 65	36,100	23,470	
	Gates, hoists, etc				735,200	10,574,970
45. Power house and tail-race excavation	Excavation—Earth	Cu. yd.	0 55	797,660	438,710	
	Earth, over depth	"	0 55	45,710	25,140	
	Dry rock	"	1 60	1,020,800	1,633,280	2,097,130
46. Highway changes	New roads	Mile	35,000 00	6·5	227,500	227,500
47. Property damages	Improvements				1,056,280	
	Lands				328,000	1,384,280
Carried forward						14,763,880

TABLE 9.—SOULANGES SECTION—RECOMMENDED PROJECT—NAVIGATION COMBINED WITH THE DEVELOPMENT OF POWER (THREE STAGE DEVELOPMENT)—*Continued*

See Plates Nos. 49–51

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	
Brought forward						14,763,880
THIRD STAGE OF POWER DEVELOPMENT, ETC.—*Con.*						
(A) WORKS PRIMARILY FOR POWER: SUBSTRUCTURES, HEAD AND TAIL-RACE EXCAVATION—*Con.*						
48. St. Timothee power house	Reconstruction				1,000,000	
	Interruption in operation	H.P. yrs.	20 00	27,000 h.p. 1 yr.	540,000	
						1,540,000
49. Power house substructure	Concrete	Cu. yd.	14 00	590,000	8,260,000	
	Gates, hoisrs, etc				2,574,350	
						10,834,350
						27,138,230
50. Engineering and contingencies	12½%					3,392,770
51. Total						30,531,000
(B) WORKS PRIMARILY FOR POWER: MACHINERY AND SUPERSTRUCTURE—						
52. Power house machinery and superstructure	Generators and turbines, 28–36,800 h.p. units				21,016,800	
	Switching				5,107,200	
	Service units and cranes				308,440	
	Superstructure				3,153,600	
						29,586,040
53. Engineering and contingencies	12½%					3,698,960
54. Total						33,285,000

Item and Description	Classification	Unit	Rate	Saving to navigation if channels made 23 ft. deep originally		Additional cost if navigation channels made 27 ft. deep originally		Cost of future enlargement from 25 ft. to 30 ft. depth	
				Quantity	Amount	Quantity	Amount	Quantity	Amount
			$		$		$		$
55. Deep water in Lake St. Francis to below Pointe au Diable	Excavation—Earth	Cu. yd.	0 65	542,020	287,310	478,890	311,280	1,213,060	788,490
	Earth, over depth	"	0 65	....	....	....	....	198,140	128,790
	Dry rock	"	1 60	150,550	240,880	145,300	232,480	....	....
	Wet rock	"	4 25	40,720	173,060	29,680	126,140	452,090	1,921,380
	Wet rock, over depth	"	4 25	13,400	56,950	20,370	86,570	101,250	430,310
56. Pointe à Biron	Excavation—Earth	Cu. yd.	0 55	98,100	53,960	97,290	53,510	276,400	152,020
	Earth, over depth	"	0 55	....	....	....	....	53,000	29,150
57. Cedars to Chamberry Gully lock	Excavation—Earth	Cu. yd.	0 55	250,000	143,000	250,000	137,500	605,000	332,750
	Earth, over depth	"	0 55	....	....	....	....	115,000	63,250
58. Chamberry Gully to Cascades lock	Excavation—Earth	Cu. yd.	0 55	79,360	43,650	76,220	41,920	184,700	101,580
	Earth, over depth	"	0 55	....	....	....	....	33,400	18,370
59. Below Cascades lock	Excavation—Earth	Cu. yd.	0 65	213,290	138,640	208,190	135,320	509,110	330,920
	Earth, over depth	"	0 65	....	....	....	....	105,000	68,250
					1,137,450	....	1,124,720	....	4,365,260
60. Engineering and contingencies	12½% approximately	....	....	....	142,550	....	140,280	....	545,740
61. Total	....	....	....	....	1,280,000	....	1,265,000	....	4,911,000

TABLE 9.—SOULANGES SECTION—RECOMMENDED PROJECT—NAVIGATION COMBINED WITH THE DEVELOPMENT OF POWER (THREE STAGE DEVELOPMENT)—*Concluded*

SUMMARY

——	Item	Amount	Total
		$	$
INITIAL STAGE: NAVIGATION AND POWER—Installed Capacity 404,300 h.p.—			
Works solely for navigation	12	31,594,000	
Works common to navigation and power	23	34,686,000	
Works primarily for power—			
Substructures, head, and tail-race excavation	27	13,079,000	
Machinery and superstructures	30	24,586,000	
			103,945,000
SECOND STAGE: POWER NORTH OF CASCADES POINT—Installed Capacity 545,000 h.p.—			
Substructure, head, and tail-race excavation	39	22,654,000	
Machinery and superstructure	42	14,637,000	37,291,000
THIRD STAGE: POWER AT CASCADES RAPIDS—Installed Capacity 1,030,400 h.p.—			
Substructure, head, and tail-race excavation	51	30,531,000	
Machinery and superstructure	54	33,285,000	
			63,816,000
TOTAL—Total installed capacity 1,979,700 h.p.			205,052,000
Cost of initial stage with 50 per cent of complete installation—202,000 h.p.			92,000,000
Saving if navigation channels made 23 feet deep originally	61		1,280,000
Additional cost if navigation channels made 27 feet deep originally	61		1,265,000
Cost of future enlargement from 25 feet depth to 30 feet depth	61		4,911,000

TABLE No. 10.—SOULANGES SECTION—RECOMMENDED PROJECT—(ILE AUX VACHES THREE STAGE)—For details, see Table No. 9

Power—1st stage—Ile aux Vaches		382,000 h.p.
2nd " North of Cascades Point		488,000 h.p.
3rd " Cascades Rapids		762,000 h.p.
1st Stage—		
Works solely for navigation	$ 31,594,000	
Works common to navigation and power	34,686,000	
Works primarily for power substructures, head and tail-race excavation	13,079,000	
Machinery and superstructures	24,586,000	
		$103,945,000
2nd Stage—		
Substructure, head and tail-race excavation	22,654,000	
Machinery and superstructure	14,637,000	
		37,291,000
3rd Stage—		
Substructure, head and tail-race excavation	30,531,000	
Machinery and superstructure	33,285,000	
		63,816,000
Total		$205,052,000

Cost of 1st stage with 50 per cent of complete installation	$ 92,000,000
Cost with double locks in flight	207,210,000
Cost with single locks in flight	204,044,000
Saving if navigation channels made 23 ft. deep originally	1,280,000
Additional cost if navigation channels made 27 ft. deep originally	1,265,000
Cost of future enlargement from 25 ft. depth to 30 ft. depth	4,911,000

Power House Installations

1st stage—26—15,550 h.p. units (22 ft. head)	404,300 h.p.
2nd " 10—54,500 " (75·5 ft. head)	545,000 h.p.
3rd " 28—36,800 " (53 ft. head)	1,030,400 h.p.
Total	1,979,700 h.p.

TABLE No. 11.—SOULANGES SECTION—TABLE SHOWING OVERALL COST OF PROJECT RECOMMENDED—(ILE AUX VACHES THREE STAGE PROJECT)

Power marketed at *40,000* h.p. per year.

Interest during construction and marketing period—5 per cent.

Construction program planned for expenditure of $10,000,000 per year.

—	First cost	Half construction period	Half market period	Interest	
Recommended Project—					
Navigation	31,594,000	2·39	....	0·124	3,920,000
1st stage—382,000 h.p.	47,765,000 24,586,000	2·35	4·77	0·418	20,000,000
2nd stage—488,000 h.p.	22,654,000 14,637,000	1·13	6·10	0·423	9,600,000
3rd stage—762,000 h.p.	30,531,000 33,285,000	1·53	9·53	0·715	21,800,000
	205,052,000				55,320,000
Add first cost					205,052,000
Total					$260,372,000

TABLE No. 12.—SOULANGES SECTION—TABLE SHOWING OVERALL COST OF PROJECT RECOMMENDED—(ILE AUX VACHES THREE STAGE PROJECT)

Power marketed at *75,000* h.p. per year.

Interest during construction and marketing period—5 per cent.

Construction program planned for expenditure of $10,000,000 per year.

—	First cost	Half construction period	Half market period	Interest	
RECOMMENDED PROJECT—					
Navigation	31,594,000	2·39	....	0·124	3,920,000
1st stage—382,000 h.p.	47,765,000 24,586,000	2·39	2·55	0·272	13,000,000
2nd stage—488,000 h.p.	22,654,000 14,637,000	1·13	3·26	0·239	5,410,000
3rd stage—762,000 h.p.	30,531,000 33,285,000	1·53	5·08	0·381	11,630,000
	205,052,000	....	....	....	33,960,000
Add first cost	....	....	....	....	205,052,000
Total	....	....	....	....	$239,012,000

TABLE No. 13.—SOULANGES SECTION—TABLE SHOWING OVERALL COST OF PROJECT RECOMMENDED—(ILE AUX VACHES THREE STAGE PROJECT)

Power marketed at *150,000* h.p. per year.

Interest during construction and marketing period—5 per cent.

Construction program planned for expenditure of $10,000,000 per year.

—	First cost	Half construction period	Half market period	Interest	
RECOMMENDED PROJECT—					
Navigation	31,594,000	2·39	....	0·124	3,920,000
1st stage—382,000 h.p.	47,765,000 24,586,000	2·39	1·27	0·196	9,360,000
2nd stage—488,000 h.p.	22,654,000 14,637,000	1·13	1·63	0·145	3,290,000
3rd stage—762,000 h.p.	30,531,000 33,285,000	1·53	2·54	0·220	6,710,000
	205,052,000				23,280,000
Add first cost	....	....	....	....	205,052,000
Total	....	....	....	....	$228,332,000

TABLE No. 14.—SOULANCES SECTION—HUNGRY BAY—MELOCHEVILLE PROJECT FOR NAVIGATION ALONE

See Plates Nos. 58–59

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
1. Channel excavation—						
(a) Deep water in Lake St. Francis to below Hungry Bay Guard Lock	Excavation—Earth	Cu. yd.	0 35	1,194,570	418,100	
	Earth, over depth	"	0 35	163,340	57,170	
	Earth	"	0 65	725,540	471,600	
	Dry rock	"	1 60	122,580	196,130	1,143,000
(b) Weir Channel at Hungry Bay Guard Lock	Excavation—Earth	Cu. yd.	0 35	499,220	174,730	
	Earth	"	0 65	96,240	62,560	
	Dry rock	"	1 60	9,450	15,120	252,410
(c) Below Hungry Bay Guard Lock to above Melocheville Flight locks	Excavation—Earth	Cu. yd.	0 45	10,716,250	4,822,320	
	Earth	"	0 65	1,351,940	878,760	
	Dry rock	"	1 60	415,600	664,960	6,366,040
(d) Above Flight Locks to Deep Water in Lake St. Louis	Excavation—Dry rock	Cu. yd.	1 60	902,910	1,444,660	
	Wet rock	"	4 25	57,390	243,910	
	Wet rock, over depth	"	4 25	6,600	28,050	1,716,620
2. Dikes—						
(a) Breakwater, Lake St. Francis	Rock fill	Cu. yd.	1 80	747,500	1,345,500	1,345,500
(b) Above Hungry Bay Guard Lock	Earth fill	Cu. yd.	0 42	119,660	50,260	
	Rock fill	"	0 60	52,830	31,700	
	Stripping	"	0 65	32,900	21,390	103,350
(c) Hungry Bay Guard Lock to Flight Locks	Earth fill	Cu. yd.	0 42	6,300,040	2,646,020	
	Earth fill	"	0 60	422,000	253,200	
	Stripping	"	0 65	1,066,540	693,250	
	Trimming	Sq. yd.	0 25	1,232,750	308,190	
	Sodding	"	0 45	155,430	69,950	
	Paving—Concrete	Cu. yd.	11 00	118,740	1,306,140	5,276,750
3. Supply Weir at Guard Lock	Concrete	Cu. yd.	11 00	3,190	35,090	
	Concrete	"	9 00	3,500	31,500	
	Foundation contingency				3,510	
	Excavation—Earth	Cu. yd.	0 65	9,560	6,220	
	Earth, trench	"	3 10	870	2,700	
Carried forward						16,203,670

TABLE No. 14—SOULANGES SECTION—HUNGRY BAY—MELOCHEVILLE PROJECT FOR NAVIGATION ALONE—*Continued*

See Plates Nos. 58—59

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						16,203,670
3. Supply Weir at Guard Lock—*Con.*	Excavation—Rock footings	Cu. yd.	2 40	1,650	3,960	
	Rock trench	"	4 10	190	780	
	Sheeting and bracing	M.F.B.M.	110 00	23·2	2,550	
	Gates, hoists, etc.				37,600	123,910
4. Hungry Bay Guard Lock and Entrance Pier	Concrete	Cu. yd.	9 00	123,880	1,114,920	
	Close drilling	Sq. ft.	0 45	27,250	12,270	
	Lock gates and operating Machine				372,000	
	Lock valves and operating machine				100,000	
	Fenders, capstans, lighting equipment, etc.				206,700	1,805,890
5. Flight locks (single flight) and Entrance Piers	Concrete	Cu. yd.	9 00	645,790	5,812,110	
	Close drilling	Sq. ft.	0 45	319,460	143,760	
	Lock gates and operating machine				982,000	
	Lock valves and operating machine				112,500	
	Emergency gate				175,000	
	Fenders, capstans, lighting equipment, etc.				350,400	
	Unwatering				108,670	7,684,440
6. Railroad diversions					271,240	271,240
7. Bridges					2,312,000	2,312,000
8. Highway changes	Third class roads	Lin. ft.	2 00	6,600	13,200	
	Macadam on banks	Sq. yd.	2 00	53,000	106,000	119,200
9. Ditches	Excavation—Earth	Cu. yd.	0 35	1,156,960	404,940	
	Bridges				31,500	436,440
10. Fences	Fencing	Rod	3 50	9,500	33,250	
	Gates	Each	18 00	168	3,030	36,280
11. Property damages	Improvements				259,050	
	Lands				610,000	869,050
12. Canal lighting and office					40,000	40,000
						29,902,120

13. Engineering and contingencies	12½ per cent					3,737,880
14. Total						33,640,000
15. Additional cost to provide double flight locks at Melocheville						3,901,000

Item and Description	Classification	Unit	Rate	Saving if navigation channels made 23 ft. deep originally		Additional cost if navigation channels made 27 ft. deep originally		Cost of future enlargement from 25 ft. to 30 ft. depth	
				Quantity	Amount	Quantity	Amount	Quantity	Amount
			$ cts.		$		$		$
16. Deep water in Lake St. Francis to deep water in Lake St. Louis	Excavation—Earth	Cu. yd.	0 35	346,480	121,270	359,190	125,720	919,060	321,670
	Earth	"	0 45	675,400	303,930	628,000	282,600	1,500,860	675,390
	Earth	"	0 65	383,970	249,580	350,500	227,830	936,340	608,620
	Earth over depth	"	0 35					165,000	57,750
	Earth over depth	"	0 45					80,000	36,000
	Earth over depth	"	0 65					323,670	210,390
	Dry rock	"	1 60	150,310	240,500	132,200	211,520		
	Wet rock	"	4 25	15,260	64,860	14,890	63,280	474,270	2,015,650
	Wet rock over depth	"	4 25					113,700	483,230
					$980,140		$910,950		$4,408,700
17. Engineering and contingencies	12½%				122,860		113,050		551,300
18. Total					$1,103,000		$1,024,000		$4,960,000

TABLE 15.—SOULANGES SECTION—NAVIGATION ALONE.—HUNGRY BAY—MELOCHEVILLE ROUTE

For details—See Table No. 14

Canal excavation	$9,478,070
Earth dykes	6,725,600
Hungry Bay guard lock and weir	1,929,800
Melocheville Locks (single flight)	7,684,440
Property damages	869,050
Bridges	2,312,000
Roads, railways and miscellaneous	903,160
Engineering and contingencies—12½%	3,737,880
Total	$33,640,000
Additional cost to provide double flight locks	$3,901,000
Saving if Navigation Channels made 23 ft. deep originally	1,103,000
Additional cost if Navigation Channels made 27 ft. deep originally	1,024,000
Cost of future enlargement from 25 ft. depth to 30 ft. depth	4,960,000

TABLE No. 16—SOULANGES SECTION—LATERAL CANAL ON NORTH SIDE OF RIVER—FOR NAVIGATION ALONE

See Plates Nos. 60–61

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
1. Channel Excavation—						
(a) Deep water in Lake St. Francis to Coteau du Lac Guard Lock.	Excavation—Earth	Cu. yd.	0 65	1,087,950	707,170	
	Dry rock	"	1 60	960,920	1,537,470	
	Dredging	"	0 65	462,550	300,660	
	Dredging overdepth	"	0 65	75,360	48,980	
	Wet rock	"	4 25	118,030	501,630	
	Wet rock overdepth	"	4 25	14,010	59,540	3,155,450
(b) Guard Lock to Chamberry Gully Lock	Excavation—Dry earth	Cu. yd.	0 55	12,327,060	6,779,880	
	Dry rock	"	1 60	574,840	919,740	7,699,620
(c) Chamberry Gully Lock to Cascades Lock	Excavation—Earth	Cu. yd.	0 55	2,365,400	1,300,970	
	Paving—Concrete	"	11 00	5,250	57,750	1,358,720
(d) Below Cascades Lock	Excavation—Earth	Cu. yd.	0 65	1,036,600	673,790	
	Earth overdepth	"	0 65	105,000	68,250	742,040
2. Dykes—						
(a) Breakwaters—Lake St. Francis	Excavation—Earth	Cu. yd.	0 65	10,960	7,120	
	Rock fill	"	1 80	415,430	747,770	
	Cribwork	"	5 00	38,730	193,650	
	Concrete	"	9 00	2,360	21,240	969,780
(b) Above Coteau de Lac Guard Lock	Earth fill	Cu. yd.	0 42	106,210	44,610	
	Rock fill	"	0 60	30,260	18,160	
	Stripping	"	0 65	23,660	15,380	
	Paving—Concrete	"	11 00	8,560	94,160	172,310
(c) Guard Lock to Chamberry Gully Lock	Earth fill	Cu. yd.	0 42	3,248,890	1,364,530	
	Rock face	"	0 90	530,580	477,520	
	Stripping	"	0 65	566,310	368,100	
	Trimming	Sq. yd.	0 25	110,660	27,670	
	Sodding	"	0 45	11,500	5,180	
	Paving—Concrete	Cu. yd.	11 00	8,150	89,650	2,332,650
(d) Chamberry Gully Lock to Cascades Lock	Earth fill	Cu. yd.	0 42	52,580	22,090	
	Stripping	"	0 65	6,980	4,540	
	Trimming	Sq. yd.	0 25	7,650	1,920	28,550
Carried forward						16,459,120

TABLE No. 16.—SOULANGES SECTION—LATERAL CANAL ON NORTH SIDE OF RIVER—FOR NAVIGATION ALONE—*Continued*

See Plates Nos. 60–61

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						16,459,120
3. Coteau du Lac Guard Lock, Entrance piers and weir	Concrete	Cu. yd.	11 00	2,750	30,250	
	Concrete	"	9 00	145,060	1,305,540	
	Foundation contingency				3,030	
	Excavation—Rock, earth, etc.				7,620	
	Lock gates and operating machinery				591,000	
	Lock valves and operating machinery				100,000	
	Sluice gates, hoists, etc.				33,800	
	Emergency dam				175,000	
	Fenders, capstans, lighting equipment, etc.				206,700	
						2,452,940
4. Guard gate, entrance piers and weir	Same as Item No. 4—Table No. 9				1,929,340	1,929,340
5. Chamberry Gully Lock, entrance piers and weir	Same as Item No. 5—Table No. 9				5,921,840	5,921,840
6. Cascades Lock, entrance piers and weir	Same as Item No. 6—Table No. 9				4,914,670	4,914,670
7. Drainage— (a) Culverts for Rivers Graisse, Rouge and Delisle					1,000,000	1,000,000
(b) Ditch—Cedars to P.L.H. & P. Co. head-race	Excavation—Earth	Cu. yd.	0 65	15,420	10,020	10,020
8. Railway bridge for C.N. Ry. at Coteau	Same as Item No. 7—Table No. 9				345,280	345,280
9. Highway changes					2,202,130	2,202,130
10. Canal lighting and offices					37,000	37,000
11. Property damages					619,290	619,290
						$35,891,630
12. Engineering and contingencies	12½%					4,486,370
13. Total						$40,378,000
14. Cost to divert canal into river when power is developed						$1,922,000
15. Cost of portion that would be abandoned when canal is diverted into river						$6,382,000

Item and Description	Classification	Unit	Rate	Saving if navigation channels made 23 ft. deep Originally		Additional cost if navigation channels made 27 ft. deep Originally		Cost of future enlargement from 25 ft. to 30 ft. depth	
				Quantity	Amount	Quantity	Amount	Quantity	Amount
			$ cts.		$		$		$
16. Lake St. Francis to Lake St. Louis	Excavation—Earth	Cu. yd.	0 65	350,750	227,990	373,540	242,800		
	Earth	"	0 55	874,440	480,940	837,940	460,870		
	Dry rock	"	1 60	193,280	309,250	203,980	326,370		
	Wet rock	"	4 25	16,560	70,380	19,800	84,150		
17. Enlargement to 30-foot depth, assuming it is done after Canal is diverted to river.	Same as Item Nos. 55—59—Table No. 9.								4,365,260
					$1,088,560		1,114,190		
18. Engineering and contingencies	12½%				136,440		140,810		545,740
19. Total					1,225,000		1,255,000		4,911,000

TABLE 17.—SOULANGES SECTION—NAVIGATION ALONE—LATERAL CANAL ON NORTH SIDE OF RIVER

For details—See Table No. 16

Canal excavation	$ 12,955,830
Earth dykes	3,503,290
Coteau du Lac guard lock and weir	2,452,940
Guard gate and weir	1,929,340
Chamberry Gully lock and weir	5,921,840
Cascades lock and weir	4,914,670
Property damages	619,290
Roads, bridges, and miscellaneous	3,594,430
Engineering and contingencies—12½ per cent	4,486,370
Total	$ 40,378,000
Cost with double locks in flight	$ 42,536,000
Cost with single locks in flight	39,370,000
Saving if navigation channels made 23 feet deep originally	1,225,000
Additional cost if navigation channels made 27 feet deep originally	1,255,000
Cost of future enlargement from 25 feet depth to 30 feet depth assuming it is done after canal is diverted to river	4,911,000
Cost to divert canal into river when power is developed	1,922,000
Cost of portion of canal that would be abandoned when canal is diverted into river	6,382,000

TABLE No. 18.—SOULANGES SECTION—NAVIGATION COMBINED WITH ALL RIVER DEVELOPMENT—CENTRE POOL ELEVATION 115

See Plates Nos. 52-53

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
WORKS SOLELY FOR NAVIGATION—						
1. Channel Excavation—						
(a) Deep water in Lake St. Francis to below Pointe au Diable	See Table No. 9—Item No. 1 (a)					4,390,350
(b) At Leonard Island	See Table No. 9—Item No. 1 (b)					772,440
(c) Approaches to Cedars Lock	Excavation—Earth	cu. yd.	0·55	323,000	177,650	
	Wet rock	"	4·25	156,380	664,620	
	Wet rock overdepth	"	4·25	45,890	195,030	
						1,037,300
(d) Approaches to Melocheville Lock	Excavation—Earth	cu. yd.	0·55	538,600	296,230	
	Dry rock	"	1 60	105,390	168,630	
	Wet rock	"	4 25	127,520	541,960	
	Wet rock overdepth	"	4 25	22,220	94,430	
						1,101,250
2. Dykes—						
(a) Breakwater—Lake St. Francis	See Table No. 9—Item No. 2 (a)					1,329,460
(b) Above Coteau du Lac	See Table No. 9—Item No. 2 (b)					379,270
(c) Above Cedars Lock—south side	Earth fill	cu. yd.	0 42	265,060	111,330	
	Rock fill	"	1 05	14,800	15,540	
	Stripping	"	0 65	29,270	19,030	145,900
3. Coteau du Lac Guard Lock and entrance piers	See Table No. 9—Item No. 3					2,803,800
4. Cedars Lock and entrance piers	Concrete	cu. yd.	9 00	236,020	2,124,180	
	Cribwork	"	5 00	113,430	567,150	
	Close drilling	sq. ft.	0 45	54,680	24,610	
	Excavation—Earth	cu. yd.	0 65	491,100	319,220	
	Rock	"	1 60	124,310	198,900	
	Gates and operating machinery				705,000	
	Valves and operating machinery				100,000	
	Emergency gate				175,000	
	Fenders, capstans, lighting equipment, etc				206,700	
						4,420,760
5. Melocheville Lock and entrance piers	Concrete	cu. yd.	9 00	334,840	3,013,560	
	Close drilling	sq. ft.	0 45	92,270	41,520	
	Excavation—Rock	cu. yd.	1 60	233,930	374,290	
	Rock trench	"	4 10	2,400	9,840	
	Gates and operating machinery				806,000	
	Valves and operating machinery				100,000	
Carried forward						16,380,530

TABLE No. 18—SOULANGES SECTION—NAVIGATION COMBINED WITH ALL RIVER DEVELOPMENT—CENTRE POOL ELEVATION 115—*Continued*

See Plates Nos. 52—53

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought foreard						16,380,530
WORKS SOLELY FOR NAVIGATION—*Con.*						
5. Melocheville Lock and entrance piers—*Con.*	Emergency gate				175,000	
	Fenders, capstans, lighting equipment, etc				206,700	
	Unwatering				604,050	5,330,960
6. Railway Bridge for C.N.Ry. at Coteau	See Table No. 9—Item No. 7					345,280
7. Highway changes	See Table No. 9—Item No. 8					134,000
8. Canal lighting and offices	See Table No. 9—Item No. 9					35,000
9. Property damages above Pointe au Diable	See Table No. 9—Item No. 10					487,040
						22,712,810
10. Engineering and contingencies	12½ per cent					2,857,190
11. Total						25,570,000
WORKS COMMON TO NAVIGATION AND POWER—						
12. Channel excavation—						
(*a*) Through Coteau Rapids	See Table No. 9—Items No. 13 (*a*) and (*b*)					6,229,650
(*b*) Pointe a Biron	See Table No. 9—Item No. 13 (*c*)					395,930
13. Dykes—						
(*a*) Coteau du Lac to Cedars Power House	Earth fill	cu. yd.	0 42	410,950	172,600	
	Earth fill	"	0 60	135,200	81,120	
	Earth fill	"	0 75	918,520	688,890	
	Rock fill	"	1 00	43,970	43,970	
	Rock fill	"	0 80	410,320	328,260	
	Stripping	"	0 65	354,470	230,410	1,545,250
(*b*) Grande Ile	See Table No. 9—Item No. 14 (*b*)					573,530
(*c*) East end of Cedars Dam to Power House	Earth fill	cu. yd.	0 60	1,318,630	791,180	
	Rock fill	"	1 00	202,390	202,390	993,570
(*d*) At St. Timothee	Earth fill	cu. yd.	0 90	77 780	70,000	
	Rock fill	"	1 80	35,010	63,020	
	Stripping	"	0 65	37,240	24,210	157,230

14. Dams at Clarke's Island	See Table No. 9—Item No. 15					1,026,630
15. Cedars Dam	Concrete	cu. yd.	11 00	631,880	6,950,680	
	Concrete	"	9 00	8,360	75,240	
	Foundation contingency				695,070	
	Excavation—Earth	cu. yd.	0 55	860,140	473,080	
	Earth trench	"	3 10	3,940	12,210	
	Rock footings	"	2 40	185,160	444,380	
	Rock trench	"	4 10	1,000	4,100	
	Unwatering				4,064,680	
	Gates, towers, hoists, etc				453,700	13,173,140
16. Cascades Dam	Concrete	Cu. yd.	11 00	319,820	3,518,020	
	Concrete	"	9 00	45,540	409,860	
	Foundation contingency				351,800	
	Excavation Rock footings	Cu. yd.	2 40	132,150	317,160	
	Earth	"	0 55	22,580	12,420	
	Earth fill	"	0 90	810,280	729,250	
	Rock fill	"	2 00	229,270	458,540	
	Stripping	"	0 65	8,110	5,270	
	Gates, hoists, etc				735,200	
	Unwatering				2,008,480	8,546,000
17. Drainage.—						
(a) Diversion of river Delisle	See table No. 9—Item No. 17 (a)					418,030
(b) Drainage for Rivers Graisse, Rouge and Delisle, including excavation Soulanges Canal.	Excavation—Walls, etc	Cu. yd.	1 60	900	1,440	
	Earth	"	0 65	622,220	404,440	
	Earth over depth	"	0 65	28,020	18,210	
	Concrete				50,000	474,090
18. Highway changes	New roads				247,120	
	Bridges				234,880	482,000
19. Property damages	Improvements				2,412,090	
	Lands				646,400	3,058,490
20. Railroad relocation—C.N. Rly. at Bellerive	See Table No. 9—Item No. 20					932,600
21. Interruption in operation of P.L.H. & P. Co		H.P.-yrs.	20 00	12,000 h.p.—2 yrs.	480,000	
				5,000 h.p.—7 yrs.	700,000	1,180,000
22. St. Timothee Power House	See Table No. 9—Item No. 48					1,540,000
						40,726,140
23. Engineering and contingencies	$12\frac{1}{2}$ per cent					5,110,860
24. Total						45,837,000

TABLE No. 18—SOULANGES SECTION—NAVIGATION COMBINED WITH ALL RIVER DEVELOPMENT—CENTRE POOL ELEVATION 115—*Continued*

See Plates Nos. 52–53.

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
WORKS PRIMARILY FOR POWER—FIRST STAGE—272,000 installed h.p. at Cascades. 631,800 installed h.p. at Cedars.						
(A) SUBSTRUCTURES, HEAD AND TAIL-RACE EXCAVATION, ETC.—						
25. Channel excavation—						
(*a*) Ile aux Vaches	Excavation—Earth	Cu. yd.	0 55	1,915,700	1,053,630	
	Earth, over depth	"	0 55	82,340	45,290	1,098,920
(*b*) Headrace and power house—Cedars	Excavation—Earth	Cu. yd.	0 55	9,878,320	5,433,080	
	Earth overdepth	"	0 55	108,810	59,850	
	Dry rock	"	1 60	134,540	215,260	5,708,190
(*c*) At St. Timothee	Excavation—Earth	Cu. yd.	1 00	516,090	516,090	
	Earth over depth	"	1 00	55,500	55,500	571,590
(*d*) Tail-race—Cascades plant	Excavation—Dry rock	Cu. yd.	1 60	478,470	765,550	
	Earth	"	0 55	274,270	150,850	
	Earth, over depth	"	0 55	21,910	12,050	928,450
26. Ice sluices, etc., at Cedars power house	Concrete	Cu. yd.	11 00	49,720	546,920	
	Concrete	"	9 00	27,500	247,500	
	Foundation contingency				54,690	
	Excavation—Earth	Cu. yd.	0 65	77,750	50,540	
	Rock trench	"	4 10	980	4,020	
	Rock footings	"	2 40	11,440	27,460	
	Gates, hoists, etc.				123,500	1,054,630
27. Power house substructure—Cedars	Concrete	Cu. yd.	14 00	578,330	8,096,620	
	Gates and racks				1,709,220	
	Unwatering				650,900	10,456,740
28. Power house substructure—Cascades	Concrete	Cu. yd.	14 00	220,780	3,090,920	
	Gates and racks				848,160	3,939,080
						23,757,600
29. Engineering and contingencies	12½ per cent					2,969,400
30. Total						26,727,000

(B) MACHINERY AND SUPERSTRUCTURES—						
31. Cedars power house	Generators and turbines—26-24300 h.p. units				16,833,600	
	Switching				3,872,960	
	Service Units and cranes				314,860	
	Superstructure				4,133,850	
						25,155,270
32. Cascades power house	Generators and turbines—8-34000 h.p. units				5,730,800	
	Switching				1,428,000	
	Service units and cranes				356,550	
	Superstructure				1,431,030	
						8,946,380
						34,101,650
33. Engineering and contingencies	12½ per cent					4,262,350
34. Total						38,364,000
SECOND STAGE—Remodelling present Cedars Plant—194,400 installed h.p.—						
(A) SUBSTRUCTURE, HEAD AND TAIL-RACE EXCAVATION—						
35. Removal of present Cedars power house	Excavation—Concrete	Cu. yd.	4 00	180,000	720,000	
	Dry rock	"	1 60	86,000	137,600	
	Wet rock	"	4 25	58,000	246,500	
	Unwatering				1,000,000	
						2,104,100
36. Power house substructure, etc	Concrete	Cu. yd.	14 00	172,040	2,408,560	
	Gates and racks				525,920	
						2,934,480
						5,038,580
37. Engineering and contingencies	12½%					629,420
38. Total						5,668,000
(B) MACHINERY AND SUPERSTRUCTURE—						
39. Power house machinery, etc	Generators and turbines—8-24,300 h.p. units				5,228,800	
	Switching				1,191,680	
	Superstructure				1,276,230	
						7,696,710
40. Engineering and contingencies	12½%					962,290
41. Total						8,659,000

TABLE No. 18—SOULANGES SECTION—NAVIGATION COMBINED WITH ALL RIVER DEVELOPMENT—CENTRE POOL ELEVATION 115—*Concluded*

See Plates Nos. 52–53

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
THIRD STAGE—Completion of Cascades Plant—850,000 installed h.p.—						
(A) SUBSTRUCTURE, HEAD AND TAIL-RACE EXCAVATION—						
42. Excavation and unwatering	Excavation—Earth	Cu. yd.	0 65	990,390	643,750	
	Earth	"	0 55	548,530	301,690	
	Earth, over depth	"	0 55	43,830	24,110	
	Dry rock	"	1 60	953,200	1,525,120	
	Unwatering				894,990	
						3,389,660
43. Completion of dam, walls, etc	Concrete	Cu. yd.	9 00	37,850	340,650	
	Excavation—Rock, footings	"	2 40	18,800	45,120	
						385,770
44. Power house substructure, etc	Concrete	Cu. yd.	14 00	463,000	6,482,000	
	Gates and racks				1,696,310	
						8,178,310
						11,953,740
45. Engineering and contingencies	12½%					1,494,260
46. Total						13,448,000
(B) MACHINERY AND SUPERSTRUCTURE—						
47. Machinery and superstructure	Generators and turbines—25-34,000 h.p.units				17,950,000	
	Switching				4,462,500	
	Superstructure				4,293,070	
						26,705,570
48. Engineering and contingencies	12½%					3,338,430
49. Total						30,044,000

SUMMARY

Works solely for navigation	Item No. 11		25,570,000
Works common to navigation and power	" 24		45,837,000
Works primarily for power—			
First Stage—Total installed capacity—903,800 h.p.			
Substructures, head and tail-race excavation, etc	" 30	26,727,000	
Machinery and superstructures	" 34	38,364,000	
			65,091,000
Second Stage—Total installed capacity, 194,400 h.p.			
Substructures, head and tail-race excavation, etc	" 38	5,668,000	
Machinery and superstructures	" 41	8,659,000	
			14,327,000
Third Stage—Total installed capacity—850,000 h.p.			
Substructure, head and tail-race excavation, etc	" 46	13,448,000	
Machinery and superstructure	" 49	30,044,000	
			43,492,000
TOTAL—Total installed capacity—1,948,200 h.p.			$194,317,000
Cost to open navigation and provide an installation of 404,300 h.p. of new power together with replacement of power lost at existing plants, i.e. 197,000 h.p. at present Cedars plant and 10,000 h.p. at other plants			$123,400,000

NOTE.—404,300 h.p.—Total installation in first stage of recommended project.

TABLE 19.—SOULANGES SECTION—NAVIGATION AND POWER—ALL RIVER DEVELOPMENT—CENTRE POOL ELEVATION 115

For details—See Table 18

POWER—1st Stage—One-quarter of Cascades Rapids and portion of Cedars		638,000 h.p.
2nd Stage—Reconstruction of present Cedars plant		180,000 h.p.
3rd Stage—Balance of Cascades Rapids		806,000 h.p.
1ST STAGE—		
Works solely for navigation	25,570,000	
Works common to navigation and power	45,837,000	
Works primarily for power—		
Substructures, head and tail-race excavation	26,727,000	
Machinery and superstructures	38,364,000	
		136,498,000
2ND STAGE—		
Substructure, head and tail-race excavation	5,668,000	
Machinery and superstructure	8,659,000	
		14,327,000
3RD STAGE—		
Substructure, head and tail-race excavation	13,448,000	
Machinery and superstructure	30,044,000	
		43,492,000
Total		$194,317,000
Cost to open navigation and provide an installation of new power equal to that in 1st Stage of recommended project, *i.e.*, 404,300 h.p.		$123,400,000

POWERHOUSE INSTALLATIONS

1st Stage—			
Cascades,	8–34,000 h.p. units (43 ft. head)	272,000	
Cedars,	26–24,300 h.p. units (32·5 ft. head)	631,000	
			903,800 h.p.
2nd Stage,	8–24,300 h.p. units (32·5 ft. head)		194,400 h.p.
3rd Stage,	25–34,000 h.p. units (43 ft. head)		850,000 h.p.
Total			1,948,200 h.p.

TABLE 20.—SOULANGES SECTION—TABLE SHOWING OVERALL COST OF ALL RIVER DEVELOPMENT—CENTRE POOL ELEVATION 115

Power marketed at 75,000 h.p. per year.
Interest during construction and marketing period, 5 per cent.
Construction program planned for expenditure of $10,000,000 per year.

—	First cost	Half Construction period	Half Market period	Interest	
	$				$
Navigation	25,570,000	3·58	....	0·192	4,910,000
1st Stage—638,000 h.p.	72,564,000 38,364,000	3·63	4·25	0·469	34,050,000
2nd Stage—180,000 h.p.	5,668,000 8,659,000	0·28	1·20	0·075	425,000
3rd Stage—806,000 h.p.	13,448,000 30,044,000	0·67	5·37	0·343	4,610,000
	194,317,000				43,995,000
Add first cost					194,317,000
Total					238,312,000

TABLE No. 21.—SOULANGES SECTION—NAVIGATION COMBINED WITH—ALL RIVER DEVELOPMENT—CENTRE POOL ELEVATION 125

See Plates Nos. 54-55

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
WORKS SOLELY FOR NAVIGATION—						
1. Channel excavation—						
(a) Deep water in Lake St. Francis to below Pointe au Diable	See Table No. 9—Item No. 1 (a)					4,390,350
(b) At Leonard Island	" " (b)					772,440
(c) Above Pointe à Biron to Chamberry Gully Lock	Excavation—Earth	Cu. yd.	0 55	3,970,000	2,183,500	
						2,183,500
(d) Chamberry Gully Lock to Cascades Lock	See Table No. 9—Item No. 1 (d)					1,358,720
(e) Below Cascades Lock	" " 1 (e)					742,040
2. Dikes—						
(a) Breakwaters—Lake St. Francis	" " 2 (a)					1,329,460
(b) Above Coteau du Lac Lock	" " 2 (b)					379,270
(c) Pointe à Biron to Chamberry Gully Lock	Earth fill	Cu. yd.	0 42	2,171,110	911,870	
	Earth fill	"	0 60	1,229,420	737,650	
	Rock fill	"	1 00	173,240	173,240	
	Stripping	"	0 65	484,110	314,670	
	Trimming	Sq. yd.	0 25	175,780	43,950	
	Sodding	"	0 45	8,460	3,810	
	Paving—Concrete	Cu. yd.	11 00	17,860	196,460	
						2,381,650
(d) Chamberry Gully Lock to Cascades Lock	See Table No. 9—Item No. 2 (d)					28,550
3. Coteau du Lac Guard Lock, etc	" " 3					2,803,800
4. Guard Gate, entrance piers and weir	" " 4					1,929,340
5. Chamberry Gully Lock, entrance piers and weir	" " 5					5,921,840
6. Cascades Lock, entrance piers and weir	" " 6					4,914,670
7. Railway bridge for C.N.Rly. at Coteau	" " 7					345,280
8. Highway changes	New roads				174,000	
	Bridges				865,830	
						1,039,830
9. Canal lighting and offices						35,000
10. Drainage ditch	Excavation—Earth	Cu. yd.	0 65	15,420	10,020	
						10,020
11. Property damages—						
(a) Above Pointe au Diable	See Table No. 9—Item No. 10					487,040
(b) Pointe à Biron to Cascades Point	Improvements				57,500	
	Lands				125,600	
						183,100
						31,235,900
12. Engineering and contingencies	12½ per cent					3,904,100
13. Total						35,140,000

TABLE No. 21.—SOULANGES SECTION—NAVIGATION COMBINED WITH ALL RIVER DEVELOPMENT—CENTRE POOL ELEVATION 125

See Plates Nos. 54–55

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
WORKS COMMON TO POWER AND NAVIGATION—						
14. Channel excavation—						
Through Coteau Rapids	See Table No. 9—Item No. 13 (a) (b)					6,229,650
15. Dikes—						
(a) Coteau du Lac to Pointe à Biron	Earth fill	Cu. yd.	0 75	674,650	505,990	
	Rock fill	"	0 80	314,710	251,770	
	Stripping	"	0 65	225,060	146,290	904,050
(b) Gradde Ile	Earth fill	Cu. yd.	0 90	559,950	503,950	
	Rock fill	"	0 84	231,440	194,410	
	Stripping	"	0 65	118,640	77,120	775,480
16. Dams at Clarke's Island	See Table No. 9—Item No. 15					1,026,630
17. Cedars Dam	Concrete	Cu. yd.	11 00	462,300	5,085,300	
	Concrete	"	9 00	44,100	396,900	
	Foundation contingency				508,530	
	Excavation—Earth	Cu. yd.	0 55	693,470	381,410	
	Rock footings	"	2 40	130,200	312,480	
	Rock trench	"	4 10	1,360	5,580	
	Unwatering				4,950,650	
	Gates, towers, hoists, etc				440,700	12,081,550
18. Drainage—						
(a) Diversion—River Delisle	See Table No. 9—Item No. 17 (a)					418.030
(b) Rivers, Graisse, Rouge and Delisle	" " 17 (b)					1,103,940
19. Highway changes	New roads					158,000
20. Property damages	Improvements				653,580	
	Lands				323,400	976,980
21. Railroad relocation—C.N. Rly. at Bellerive	See Table No. 9—Item No. 20					932,600
22. Interruption in operation of P.L.H. & P.Co	See Table No. 9—Item No. 21					480,000
						25,086,910
23. Engineering and contingencies	12½ per cent					3,135,090
24. Total						28,222,000
WORKS PRIMARILY FOR POWER—FIRST STAGE—*Pointe* a Biron—559,800 installed h.p.—						
(A) SUBSTRUCTURES, HEAD AND TAIL-RACE EXCAVATION, ETC.						
25. Head and tail-race excavation	Excavation—Earth	Cu. yd.	0 55	2,429,780	1,336,380	

	Earth	"	0 65	468,390	304,450	
	Earth	"	1 00	1,200,070	1,200,070	
	Earth	"	0 80	7,708,110	6,166,490	
	Earth, overdepth	"	1 00	114,070	114,070	
	Earth over depth	"	0 80	425,920	340,740	
	Dry rock	"	1 60	975,970	1,561,550	
	Unwatering				366,680	
						11,390,430
26. Power house substructure	Concrete	Cu. yd.	14 00	624,030	8,736,420	
	Gates and racks				2,692,980	11,429,400
						22,819,830
27. Engineering and contingencies	12½ per cent					2,852,170
28. Total						25,672,000
(B) MACHINERY AND SUPERSTRUCTURES—						
29. Machinery, etc	Generators and turbines—36-15,550 h.p. units				22,017,600	
	Switching				3,715,200	
	Service units and cranes				536,740	
	Superstructure				3,752,360	
						30,021,900
30. Engineering and contingencies	12½ per cent					3,752,100
31. Total						33,774,000
SECOND STAGE—Cascades Island—1,398,400 installed h.p.—						
(A) SUBSTRUCTURES, HEAD AND TAIL-RACE EXCAVATION, ETC.—						
32. Removal of present Cedars power house						480,000
33. Dam at Cascades Island	Concrete	Cu. yd.	11 00	417,680	4,594,480	
	Concrete	"	9 00	129,490	1,165,410	
	Foundation contingency				459,450	
	Excavation—Rock footings	Cu. yd.	2 40	170,600	409,440	
	Earth	"	0 65	22,580	14,680	
	Gates, hoists, etc				735,200	
	Unwatering				2,926,940	
	Earth fill	Cu. yd.	0 90	153,360	138,020	
	Rock fill	"	2 00	62,280	124,560	
	Stripping	"	0 65	36,100	23,470	
						10,591,650
34. Power house and tail-race excavation	Excavation—Earth	Cu. yd.	0 55	822,800	452,540	
	Earth, over depth	"	0 55	65,740	36,160	
	Dry rock	"	1 60	1,478,440	2,365,500	
						2,854,200
35. Highway changes	See Table No. 9—Item No. 46					227,500
36. Property damages	" 9— " 47					1,384,280
37. St. Timothee power house	" 9— " 48					1,540,000
Carried forward						17,077,630

TABLE 21.—SOULANGES SECTION—NAVIGATION COMBINED WITH ALL RIVER DEVELOPMENT—CANTRE POOL ELEVATION 125—*Concluded*

See Plates Nos. 54—55

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						17,077,630
(A) SUPSTRCTURES HEAD AND TAIL-RACE EXCAVATION, ETC.—*Con.*						
38. Power house substructure	Concrete	Cu. yd.	14 00	797,750	11,168,500	
	Gates and racks				3,493,780	
						14,662,280
						$ 31,739,910
39. Engineering and contingencies	12½%					3,967,090
40. Total						$ 35,707,000
(B) MACHINERY AND SUPERSTRUCTURE—						
41. Machinery, etc	Generators and turbines—38-36,800 h.p. units				28,522,800	
	Switching				6,931,200	
	Service units and cranes				366,950	
	Superstructure				4,336,200	
						40,157,150
42. Engineering and contingencies	12½%					5,019,850
43. Total						45,177,000

SUMMARY

Works solely for navigation	Item No. 13		35,140,000
Works common to navigation and power	" 24		28,222,000
Works primarily for power—			
First Stage—Total installed capacity—559,800 h.p.			
Substructures, head and tail-race excavation, etc	" 28	25,672,000	
Machinery and superstructures	" 31	33,774,000	
			59,446,000
Second Stage—Total installed capacity—1,398,400 h.p.			
Substructures, head and tail-race excavation, etc	" 40	35,707,000	
Machinery and superstructures	" 43	45,177,000	
			80,884,000
TOTAL—Total installed capacity—1,958,200 h.p.			$203,692,000
Cost to open navigation and provide an installation of 404,300 h.p. of new power			$113,687,000

NOTE.—404,300 h.p.—Total installation in first stage of recommended project.

TABLE 22.—SOULANGES SECTION—NAVIGATION AND POWER—ALL RIVER DEVELOPMENT—CENTRE POOL ELEVATION 125

For details—See Table 21

Power—1st Stage—Pointe à Biron		516,000 h.p.
2nd Stage—Cascades Rapids		1,113,000 h.p.
1st Stage—		
Works solely for navigation	$ 35,140,000	
Works common to navigation and power	28,222,000	
Works primarily for power—		
Substructures, head and tail-race excavation	25,672,000	
Machinery and superstructures	33,774,000	
		$122,808,000
2nd Stage—		
Substructure, head and tail-race excavation	$ 35,707,000	
Machinery and superstructure	45,177,000	
		80,884,000
Total		$203,692,000
Cost to open navigation and provide an installation of new power equal to that in 1st Stage of recommended project, *i.e.*, 404,300 h.p.		$113,687,000

Power House Installations

1st Stage—36–15,500 h.p. units (22 ft. head)	559,800 h.p.
2nd Stage—38–36,800 h.p. units (53 ft. head)	1,398,400 h.p.
Total	1,958,200 h.p.

TABLE 23.—SOULANGES SECTION—POWER ALONE—AS IN RECOMMENDED PROJECT (ILE AUX VACHES THREE STAGE DEVELOPMENT)

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
FIRST STAGE—Ile aux Vaches—404,300 installed h.p.						
(A) Coteau Rapids Enlargement—						
1. Channel from above Clarke's Island to below Broad Island	See Table No. 9—Item No. 13 (a)					5,046,260
2. Round Island channel	See Table No. 9—Item No. 13 (b)					1,183,390
3. Dams at Clarke's Island	See Table No. 9—Table No. 15					1,026,630
4. Railroad relocation C.N. Ry. at Bellerive	See Table No. 9—Item No. 20					932,600
5. Property Damages						50,000
						8,238,880
6. Engineering and contingencies	12½%					1,029,120
7. Total						9,268,000
(B) Revision of 14 ft. Navigation—						
8. Excavation for Canal	Excavation—Earth	Cu. yd.	0 65	2,440,500	1,586,330	
	Dry rock	"	1 60	120,850	193,360	1,779,690
9. Guard gate and weir above Chamberry Gully Lock	Concrete	Cu. yd.	11 00	2,520	27,720	
	Concrete	"	9 00	9,000	81,000	
	Foundation contingency				2,770	
	Cribwork	Cu. yd.	5 00	8,800	44,000	
	Excavation—Earth	"	0 65	6,520	4,240	
	Round bearing piles	lin. ft.	0 85	34,710	29,500	
	Steel Sheet Piling	tons	100 00	209	20,900	
	Lock gates, etc				11,000	
	Sluice gates, etc				18,900	240,030
10. Chamberry Gully and Cascades Locks	Concrete	Cu. yd.	9 00	98,640	887,760	
	Cribwork	"	5 00	19,920	99,600	
	Gates, etc				105,000	1,092,360
11. Regulating weirs	Concrete	Cu. yd.	11 00	11,050	121,550	
	Concrete	Cu. yd.	9 00	51,640	464,760	
	Foundation contingencies				12,150	
	Excavation—Rock	Cu. yd.	1 60	2,550	4,080	
	Rock trench	"	4 10	1,360	5,570	
	Earth	"	0 65	133,500	86,780	
	Earth trench	"	3 10	7,990	24,770	
	Sheeting and bracing	M ft. B.M.	110 00	127	13,970	
	Gates, hoists, etc				35,550	769,180

12. Dykes	Earth fill	cu. yd.	0 60	2,913,260	1,747,960	
	Rock fill	"	1 05	49,760	52,250	
	Rock fill	"	1 00	76,320	76,320	
	Stripping	"	0 65	402,210	261,440	
	Trimming	Sq. yd.	0 25	175,780	43,950	
	Sodding	"	0 45	8,460	3,810	
	Paving—Concrete	Cu. yd.	11 00	12,480	137,280	2,323,010
13. Bridges						150,000
14. Property damages	Lands				56,000	56,000
						6,410,270
15. Engineering and contingencies	12½%					801,730
16. Total						7,212,000
(C) SUBSTRUCTURES, DAM, HEAD AND TAIL-RACE EXCAVATION, ETC.						
17. Channel Excavation—						
(a) Pte. à Biron	See Table No. 9—Item No. 13 (c)					395,930
(b) Channel through lower end of Grande Ile	See Table No. 9—Item No. 25					750,080
18. Dykes—						
(a) Coteau du Lac to Cedars	See Table No. 9—Item No. 14 (a)					1,197,470
(b) Grand Ile	See Table No. 4—Item No. 14 (b)					573,530
19. Cedars dam	See Table No. 9—Item No. 16					15,205,030
20. Drainage	See Table No. 9—Item No. 17 (a), (b) and (c)					1,531,990
21. Highway changes	New roads					158,000
22. Property damages	Improvements				603,580	
	Lands				323,400	
						926,980
23. Interruption in operation of P.L.H. & P. Co	See Table No. 9—Item No. 21					480,000
24. Substructures—Ile aux Vaches Power Houses	See Table No. 9—Item No. 24					10,875,550
						32,094,560
25. Engineering and contingencies	12½%					4,011,440
26. Total						36,106,000
(D) MACHINERY AND SUPERSTRUCTURE—						
27. Total	See Table No. 9—Item No. 30					24,586,000
SECOND STAGE—Power House North of Cascades Pt.—545,000 installed h.p.—						
(A) SUBSTRUCTURE, HEAD AND TAIL-RACE EXCAVATION—						
28. Head-race—Cedars to Power House	Excavation—Earth	Cu. yd.	0 55	17,408,000	9,574,400	9,574,400
29. Tail-race and power house excavation	See Table No. 9—Item No. 32					1,727,620
Carried forward						11,302,020

TABLE 23.—SOULANGES SECTION—POWER ALONE—AS IN RECOMMENDED PROJECT (ILE AUX VACHES THREE STAGE DEVELOPMENT)—*Concluded*

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Carried forward						11,302,020
SECOND STAGE, Etc.—*Con.*						
(A) SUBSTRUCTURE HEAD AND TAIL-RACE EXCAVATION, ETC.—*Con.*						
30. Dykes—Cedars to power house	Earth fill	Cu. yd.	0 42	5,010,620	2,104,470	
	Rock fill	"	1 10	51,770	56,950	
	Rock fill	"	1 00	277,250	277,250	
	Stripping	"	0 65	600,300	390,200	
						2,828,870
31. Ice sluices and walls at power house	See Table No. 9—Item No. 34					1,551,290
32. Power house substructure	See Table No. 9—Item No. 35					5,269,970
33. Highway changes	New roads				150,000	
	Bridges				442,000	
						592,000
34. Property damages	Improvements				565,210	
	Lands	acre	200 00	945	189,000	
						754,210
						22,298,360
35. Engineering and contingencies	12½%					2,787,640
36. Total						25,086,000
(B) MACHINERY AND SUPERSTRUCTURE—						
37. Total	See Table No. 9—Item No. 42					14,637,000
THIRD STAGE—Dam and Power House at Cascades Rapids—1,030,400 installed h.p.—						
(A) SUBSTRUCTURE, HEAD AND TAIL-RACE EXCAVATION, ETC.						
38. Total	See Table No. 9—Item No. 51					30,531,000
(B) MACHINERY AND SUPERSTRUCTURE—						
39. Total	See Table No. 9—Item No. 54					33,285,000

SUMMARY

FIRST STAGE—Power at Ile aux Vaches—Installed capacity 404,300 h.p.—			
Coteau Rapids enlargement	Item No. 7	$ 9,268,000	
Revision of 14-ft. navigation	" 16	7,212,000	
Substructures, dam, head and tail-race excavation, etc	" 26	36,106,000	
Machinery and superstructure	" 27	24,586,000	
			$ 77,172,000
SECOND STAGE—Power north of Cascades Point—Installed capacity 545,000 h.p.—			
Substructures, head and tail-race excavation, etc	Item No. 36	25,086,000	
Machinery and superstructure	" 37	14,637,000	
			39,723,000
THIRD STAGE—Power at Cascades Rapids—Installed capacity 1,030,400 h.p.—			
Substructures, head and tail-race excavation, etc	Item No. 38	30,531,000	
Machinery and superstructure	" 39	33,285,000	
			63,816,000
TOTAL—Total installed capacity—1,979,700 h.p.			$ 180,711,000

TABLE 24.—SOULANGES SECTION—POWER ALONE—ILE AUX VACHES—THREE-STAGE PROJECT

For details—See Table 23

1st Stage—Ile aux Vaches	382,000 h.p.
2nd Stage—North of Cascades Point	488,000 h.p.
3rd Stage—Cascades Rapids	762,000 h.p.

1st Stage—		
Coteau Rapids enlargement	$ 9,268,000	
Revision of 14-ft. navigation	7,212,000	
Substructures, dams, head and tail-race excavation	36,106,000	
Machinery and superstructures	24,586,000	
		$ 77,172,000
2nd Stage—		
Substructure, head and tail-race excavation	$ 25,086,000	
Machinery and superstructure	14,637,000	
		39,723,000
3rd Stage—		
Substructure, head and tail-race excavation	$ 30,531,000	
Machinery and superstructure	33,285,000	
		63,816,000
Total		$180,711,000

Power House Installations

1st Stage—26–15,550 h.p. units (22 ft. head)	404,300 h.p.
2nd Stage—10–54,500 h.p. units (75·5 ft. head)	545,000 h.p.
3rd Stage—28–36,800 h.p. units (53 ft. head)	1,030,400 h.p.
Total	1,979,700 h.p.

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TABLE No. 25.—SOULANGES SECTION—NAVIGATION COMBINED WITH PARTIAL POWER DEVELOPMENT—HUNGRY BAY—MELOCHEVILLE ROUTE

Balance of Power as in Recommended Project—(Ile aux Vaches Three Stage)
NOTE.—Navigation and 1st Stage of Power Development Shown on Plates 56-57

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
WORKS SOLELY FOR NAVIGATION—						
1. Channel excavation—						
(a) Deep water in Lake St. Francis to below Hungry Bay guard lock.	Excavation—Earth	cu. yd.	0·35	1,471,670	515,090	
	Earth over depth	"	0 35	163,340	57,170	
	Earth	"	0 65	748,810	486,730	
	Dry rock	"	1 60	131,950	211,120	
						1,270,110
(b) Above flight locks to deep water in Lake St. Louis	Excavation—Earth	cu. yd.	0 45	902,000	405,900	
	Dry rock	"	1 60	1,075,210	1,720,340	
	Wet rock	"	4 25	57,390	243,910	
	Wet rock over depth	"	4 25	6,600	28,050	2,398,200
2. Breakwater, Lake St. Francis	See Table No. 14—Item No. 2 (a)					1,345,500
3. Hungry Bay guard lock and entrance piers	See Table No. 14—Item No. 4					1,805,890
4. Flight locks (single flight) and entrance piers	See Table No. 14—Item No. 5					7,684,440
5. Bridges						2,099,450
6. Property damages	Improvements				161,010	
	Lands				100,000	
						261,010
7. Canal lighting and office						40,000
						16,904,600
8. Engineering and contingencies	12½ per cent					2,113,400
9. Total						19,018,000
WORKS COMMON TO NAVIGATION AND POWER—						
10. Channel excavation—						
Below Hungry Bay guard lock to above flight locks	Excavation—Earth	cu. yd.	0 45	22,403,910	10,081,760	
	Earth	"	0 65	5,237,650	3,404,480	
	Dry rock	"	1 60	1,206,980	1,931,170	
						15,417,410
11. Dykes—Below guard lock to above flight lock	Earth fill	cu. yd.	0 42	6,614,770	2,778,210	
	Earth fill	"	0 60	422,000	253,200	
	Rock fill	"	0 60	60,590	36,360	
	Stripping	"	0 65	1,122,960	729,930	
	Trimming	sq. yd.	0 25	1,255,130	313,780	
	Sodding	"	0 45	157,740	70,980	
	Paving—concrete	cu. yd.	11 00	128,980	1,418,780	
						5,601,240
Carried forward						21,018,650

TABLE 25—SOULANGES SECTION—NAVIGATION COMBINED WITH PARTIAL POWER DEVELOPMENT—HUNGRY BAY—MELOCHEVILLE ROUTE—*Continued*

Balance of Power as in Recommended Project—(Ile aux Vaches Three Stage)
NOTE—Navigation and 1st Stage of Power Development Shown on Plates 56-57

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						21,018,650
WORKS COMMON TO NAVIGATION AND POWER—*Con.*						
12. Supply weir south of guard lock	Concrete	cu. yd.	11 00	18,480	203,280	
	Concrete	"	9 00	9,150	82,350	
	Foundation contingency				20,330	
	Excavation—Earth	cu. yd.	0 65	15,000	9,750	
	Rock footings	"	2 40	6,600	15,840	
	Trench earth	"	3 10	4,050	12,560	
	Trench rock	"	4 10	880	3,610	
	Sheeting and bracing	M.F.B.M.	110 00	108	11,880	
	Gates, hoists, etc				132,900	492,500
13. Railroad diversions						274,940
14. Highway changes	See Table No. 14—Item No. 8					119,200
15. Ditches	See Table No. 14—Item No. 9					436,440
16. Fences	See Table No. 14—Item No. 10					36,280
17. Property damages	Improvements				98,040	
	Lands				506,000	604,040
						22,982,050
18. Engineering and contingencies	12½ per cent					2,872,950
19. Total						25,855,000
WORKS PRIMARILY FOR POWER—FIRST STAGE—MELOCHEVILLE—Installed capacity, 283,800 h.p.—						
(A) SUBSTRUCTURE, HEAD AND TAIL-RACE EXCAVATION, ETC.—						
20. Channel excavation—						
(*a*) Deep water in Lake St. Francis to below supply weir	Excavation—Earth	cu. yd.	0 35	163,170	57,110	
	Earth	"	0 65	1,555,390	1,011,000	
	Earth over depth	"	0 65	30,560	19,860	
	Dry rock	"	1 60	550,460	880,740	
	Wet rock	"	4 25	798,670	3,394,250	
	Wet rock over depth	"	4 25	58,340	247,950	5,611,010
(*b*) Above flight locks to power house	Excavation—Earth	cu. yd.	0 45	2,310,120	1,039,550	
	Earth	"	0 65	22,260	14,470	
	Dry Rock	"	1 60	1,075,210	1,720,340	2,774,360

(c) Tail-race	Excavation—Dry rock	cu. yd.	1 60	822,860	1,316,580	
	Wet rock	"	4 25	225,950	960,290	
	Over depth	"	4 25	21,180	90,020	
						2,366,890
21. Control works in Coteau Rapids	Concrete	Cu. yd.	11 00	14,040	154,440	
	Concrete	"	9 00	1,360	12,240	
	Foundation contingency				15,440	
	Excavation—Rock footings	Cu. yd.	2 40	9,360	22,470	
	Earth	"	0 65	6,000	3,900	
	Gates, hoists, etc				151,400	
	Cribwork	Cu. yd.	5 00	12,000	60,000	
	Unwatering				200,400	
						620,290
22. Ice sluices and walls at power house	Concrete	cu. yd.	11 00	11,760	129,360	
	Concrete	"	9 00	83,420	750,780	
	Foundation contingency				12,940	
	Excavation—Dry rock	Cu. yd.	1 60	3,450	5,520	
	Gates, hoists, etc				37,700	
						936,300
23. Power house substructure	Concrete	Cu. yd.	14 00	141,570	1,981,980	
	Gates and racks				424,300	
						2,406,280
24. Bridge aobe power house						215,540
25. Property damages	Improvements				26,450	
	Lands				100 000	126,450
						15,057,120
26. Engineering and contingencies	12½ per cent					1,882,880
27. Total						16,940,000
(B) MACHINERY AND SUPERSTRUCTURE—						
28. Machinery, etc	Generators and turbines—6—47,300 h.p. units.				4,551,120	
	Switching				1,152,000	
	Service units and cranes				152,400	
	Superstructure				914,640	
						6,770,160
29 Engineering and contingencies	12½ per cent					846,840
30. Total						7,617,000
SECOND STAGE—ILE AUX VACHES—404,300 Installed h.p.						
(A) COTEAU RAPIDS ENLARGEMENT—						
31. Same as Table No. 23—Item No. 7, less $4,422,000						4,846,000

TABLE No. 25—SOULANGES SECTION—NAVIGATION COMBINED WITH PARTIAL POWER DEVELOPMENT—HUNGRY BAY—MELOCHEVILLE ROUTE—*Concluded*

Balance of Power as in Recommended in Project—(Ile aux Vaches Three Stages)
NOTE—Navigation and 1st Stage of Power Development Shown on Plates 56-57.

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
SECOND STAGE, Etc.—*Con.*						
(B) SUBSTRUCTURES, DAM, HEAD AND TAIL-RACE EXCAVATION, ETC.—						
32. Same as Table No. 23—Item No. 26, less $558,000 due to decrease in cost of unwatering Cedars Dam						35,548,000
(C) MACHINERY AND SUPERSTRUCTURE—						
33. See Table No. 9—Item No. 30						24,586,000
THIRD STAGE—NORTH OF CASCADES POINT—327,000 installed h.p.—						
(A) SUPERSTRUCTURE, HEAD AND TAIL-RACE EXCAVATION—						
34. Head-race, Cedars to power house	Excavation—Earth	Cu. yd.	0 55	8,435,640	4,639,600	4,639,600
35. Tail-race and power house excavation	Excavation—Earth	Cu. yd.	0 55	1,210,000	665,500	
	Earth, over depth	"	0 55	67,000	36,850	
	Dry rock	"	1 60	8,900	14,240	
	Wet rock	"	4 25	14,000	59,500	
	Wet rock over depth	"	4 25	4,800	20,400	
	Unwatering				450,800	
						1,247,290
36. Dikes—above power house	See Table No. 23—Item No. 30					2,828,870
37. Ice sluices and walls at power house	See Table No. 9—Item No. 34					1,551,290
38. Power house substructure	Concrete	Cu. yd.	14 00	190,080	2,661,120	
	Gates and racks				607,290	
						3,268,410
39. Highway changes	See Table No. 23—Item No. 33					592,000
40. Property damages	See Table No. 23—Item No. 34					754,210
						14,881,670
41. Engineering and contingencies	12½ per cent					1,860,330
42. Total						16,742,000
(B) MACHINERY AND SUPERSTRUCTURE—						
43. Machinery and superstructure	Generators and turbines—6-54,500 h.p. units				5,273,820	
	Switching				1,332,000	
	Service units and cranes				219,640	
	Superstructure				1,113,480	
						7,938,940

44. Engineering and contingencies	12½ per cent					992,060
45. Total						8,931,000
FOURTH STAGE—CASCADES RAPIDS—1,030,400 installed h.p.—						
(A) SUBSTRUCTURE, HEAD AND TAIL-RACE EXCAVATION—						
46. Same as Table No. 9—Item No. 51, less $366,000 due to decrease in cost of unwatering Cascades Dam						30,165,000
(B) MACHINERY AND SUPERSTRUCTURE—						
47. See Table No. 9—Item No. 54						33,285,000

SUMMARY

FIRST STAGE—NAVIGATION AND POWER VIA HUNGRY BAY—MELOCHEVILLE—Installed capacity 283,800 h.p.—			
Works solely for navigation	Item No. 9	19,018,000	
Works common to navigation and power	" 19	25,855,000	
Works primarily for power.——			
Substructure, head and tail-race excavation, etc	" 27	16,940,000	
Machinery and superstructure	" 30	7,617,000	
			69,430,000
SECOND STAGE—POWER AT ILE AUX VACHES—Installed capacity 404,300 h.p.—			
Coreau rapids enlargement	Item No. 31	4,846,000	
Substructures, head and tail-race excavation, etc	" 32	35,548,000	
Machinery and superstructure	" 33	24,586,000	
			64,980,000
THIRD STAGE—POWER AT CASCADES POINT—Installed capacity—327,000 h.p....—			
Substructure, head and tail-race excavation, etc	Item No. 42	16,742,000	
Machinery and superstructure	" 45	8,931,000	
			25,673,000
FOURTH STAGE—POWER AT CASCADES ISLAND—Installed capacity—1,030,400 h.p.—			
Substructure, head and tail-race excavation, etc	Item No. 46	30,165,000	
Machinery and superstructure	" 47	33,285,000	
			63,450,000
TOTAL—Total installed capacity—2,045,500 h.p			223,533,000

TABLE 26.—SOULANGES SECTION—NAVIGATION AND PARTIAL POWER DEVELOPMENT VIA HUNGRY BAY-MELOCHEVILLE—BALANCE OF POWER AS IN RECOMMENDED PROJECT

Diversion to Melocheville for Power, 15,500 c.f.s.

NAVIGATION—Via Hungry Bay—Melocheville route.		
POWER—Four-stage development—		
1st Stage—Melocheville		116,000 h.p.
2nd Stage—Ile aux Vaches		370,000 h.p.
3 Stage—North of Cascades Point		384,000 h.p.
4th Stage—Cascades Rapids		762,000 h.p.
1ST STAGE—		
Works solely for navigation (single flight locks)	$ 19,676,000	
Works common to navigation and power	17,048,000	
Works primarily for power—		
Substructure, head and tail-race excavation	9,199,000	
Machinery and superstructure	3,945,000	
		$ 49,868,000
2ND STAGE—		
Coteau Rapids enlargement	$ 7,108,000	
Substructures, head and tail-race excavation, etc	35,834,000	
Machinery and superstructures	24,586,000	
		67,528,000
3RD STAGE—		
Substructure, head and tail-race excavation	$ 20,734,000	
Machinery and superstructure	11,742,000	
		32,476,000
4TH STAGE—		
Substructure, head and tail-race excavation	$ 30,352,000	
Machinery and superstructure	33,285,000	
		63,637,000
Total		$213,509,000

POWER HOUSE INSTALLATIONS

1st Stage— 3–47,300 h.p. units (77·5 ft. head)	141,900 h.p.
2nd Stage—26–15,550 h.p. units (22 ft. head)	404,300 h.p.
3rd Stage— 8–54,500 h.p. units (75·5 ft. head)	436,000 h.p.
4th Stage—28–36,800 h.p. units (53 ft. head)	1,030,400 h.p.
Total	2,012,600 h.p.

TABLE 27.—SOULANGES SECTION—NAVIGATION AND PARTIAL POWER DEVELOPMENT VIA HUNGRY BAY-MELOCHEVILLE—BALANCE OF POWER AS IN RECOMMENDED PROJECT

Diversion to Melocheville for Power, 31,800 c.f.s.

For details—See Table 25

NAVIGATION—Via Hungry Bay-Melocheville route.		
POWER—Four-stage development—		
1st Stage—Melocheville		239,000 h.p.
2nd Stage—Ile aux Vaches		370,000 h.p.
3rd Stage—North of Cascades Point		261,000 h.p.
4th Stage—Cascades Rapids		762,000 h.p.
1ST STAGE—		
Works solely for navigation	$ 19,018,000	
Works common to navigation and power	25,855,000	
Works primarily for power—		
Substructure, head and tail-race excavation	16,940,000	
Machinery and superstructure	7,617,000	
		$ 69,430,000
2ND STAGE—		
Coteau Rapids enlargement	$ 4,846,000	
Substructures, head and tail-race excavation, etc	35,548,000	
Machinery and superstructures	24,586,000	
		64,980,000
3RD STAGE—		
Substructure, head and tail-race excavation	$ 16,742,000	
Machinery and superstructure	8,931,000	
		25,673,000
4TH STAGE—		
Substructure, head and tail-race excavation	$ 30,165,000	
Machinery and Superstructure	33,285,000	
		63,450,000
Total		$223,533,000

TABLE 27—*Con.*—POWER HOUSE INSTALLATIONS

1st Stage— 6–47,300 h.p. units (77·5 ft. head)	283,800 h.p.
2nd Stage—26–15,550 h.p. units (22 ft. head)	404,300 h.p.
3rd Stage— 6–54,500 h.p. units (75·5 ft. head)	327,000 h.p.
4th Stage—28–36,800 h.p. units (53 ft. head)	1,030,400 h.p.
Total	2,045,500 h.p.

TABLE 28.—SOULANGES SECTION—NAVIGATION AND PARTIAL POWER DEVELOPMENT VIA HUNGRY BAY-MELOCHEVILLE—BALANCE OF POWER AS IN 1ST AND 3RD STAGES OF RECOMMENDED PROJECT

Diversion to Melocheville for Power, 66,700 c.f.s.

NAVIGATION—Via Hungry Bay-Melocheville route.		
POWER—Three-stage development—		
1st Stage—Melocheville		500,000 h.p.
2nd Stage—Ile aux Vaches		370,000 h.p.
3rd Stage—Cascades Rapids		762,000 h.p.
1ST STAGE—		
Works solely for navigation	$ 19,873,000	
Works common to navigation and power	44,594,000	
Works primarily for power—		
Substructure, head and tail-race excavation	33,719,000	
Machinery and superstructure	15,143,000	
2ND STAGE—		$113,329,000
Coteau Rapids enlargement	$ 1,763,000	
Substructures, head and tail-race excavation, etc	34,936,000	
Machinery and superstructures	24,586,000	
3RD STAGE—		61,285,000
Substructure, head and tail-race excavation	29,879,000	
Machinery and superstructure	33,285,000	
		63,164,000
Total		$237,778,000

POWER HOUSE INSTALLATIONS

1st Stage—12–47,300 h.p. units (77·5 ft. head)	567,600 h.p.
2nd Stage—26–15,550 h.p. units (22 ft head)	404,300 h.p.
3rd Stage—28–36,800 h.p. units (53 ft. head)	1,030,400 h.p.
Total	2,002,300 h.p.

TABLE No. 29.—SOULANGES SECTION—TABLE SHOWING RELATIVE OVERALL COST OF SCHEMES OF IMPROVEMENT

Interest during construction and marketing period at 5%.
Construction program planned for expenditure of $10,000,000 per year.

"A"—Recommended Project—Ile aux Vaches Three Stage Project. (See Tables Nos. 9, 10, 11, 12 and 13.)
"B"—Separate Navigation & Power Works. Navigation via Hungry Bay—Melochville Route. Power as in Recommended Scheme—Ile aux Vaches Three Stage Project.
"C"—Four Stage Project—15,500 c.f.s. via Hungry Bay—Melocheville (Canal 300′ x 25′—Vel. 2·0 f.s.). Balance of Power as in Recommended Project. (See Table No. 26).
"D"—Four Stage Project—31,800 c.f.s. via Hungry Bay—Melocheville (Canal 360′ x 35′—Vel. 2¼ f.s.). Balance of Power as in Recommended Project (See Table No. 27).
"E"—Three Stage Project—66,700 c.f.s. via Hungry Bay—Melocheville (Canal 790′ x 35′—Vel. 2¼ f.s.). Balance of Power as in 1st and 3rd Stages of Recommended Project. (See Table No. 28).

—	"A"	"B"	"C"	"D"	"E"
1. Assuming no transfer of power between Provinces—					
(a) Power marketed at 40,000 h.p. per year	260,372,000	263,239,000	265,629,000	276,293,000	319,958,000
(b) Power marketed at 75,000 h.p. per year	239,012,000	241,869,000	246,159,000	256,713,000	290,888,000
(c) Power marketed at 150,000 h.p. per year	228,332,000	231,069,000	236,379,000	246,843,000	276,198,000
2. Assuming Quebec supplied with 200,000 h.p. from International Section—					
(a) Power marketed at 40,000 h.p. per year	281,042,000	265,239,000	267,629,000	278,293,000	321,958,000
(b) Power marketed at 75,000 h.p. per year	249,512,000	243,869,000	248,159,000	258,713,000	292,888,000
(c) Power marketed at 150,000 h.p. per year	234,102,000	233,069,000	238,379,000	248,843,000	278,198,000

NOTE.—$2,000,000 has been added to Schemes "B," "C," "D," and "E" as the difference in value of the navigation canal via Hungry Bay-Melocheville over that of the Recommended Project.
$2,000,000 has been added to all Schemes under No. 2 to cover cost of renewing generators in Barn-Island Power House from 60 cycles to 25 cycles.

TABLE No. 30.—LACHINE SECTION—RECOMMENDED PROJECT—NAVIGATION ALONE

See Plates Nos. 62–64

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
1. Channel excavation—						
(a) Deep water in Lake St. Louis to Lachine Wharf	Excavation—Earth	Cu. yd.	0 65	3,728,700	2,423,660	
	Earth, over depth	"	0 65	257,680	167,490	
	Wet rock	"	3 00	294,100	882,300	
	Wet rock, over depth	"	3 00	33,340	100,020	
	Wet rock	"	4 25	221,500	941,380	
	Wet rock, over depth	"	4 25	56,510	240,170	4,755,020
(b) Lachine Wharf to Verdun Lock	Excavation—Earth	Cu. yd.	0 65	5,907,980	3,840,190	
	Dry rock	"	1 20	837,630	1,005,160	
	Dry rock	"	1 60	122,010	195,220	
	Wet rock	"	3 00	274,700	824,100	
	Wet rock	"	4 25	91,570	389,170	
	Wet rock, over depth	"	4 25	62,300	264,770	
	Close drilling	Sq. ft.	0 45	79,300	35,690	6,554,300
(c) Above guard gate to control dam	Excavation—Earth	Cu. yd.	0 65	889,200	577,980	
	Dry rock	"	1 20	163,000	195,600	773,580
(d) Verdun Lock to Nun's Island Lock	Excavation—Earth	Cu. yd.	0 65	645,820	419,780	
	Rock	"	1 20	255,120	306,140	
	Close drilling	Sq. ft.	0 45	38,630	17,380	743,300
(e) Nun's Island Lock to Montreal Lock	Excavation—Earth	Cu. yd.	0 65	372,120	241,880	
	Rock	"	1 20	972,550	1,167,060	
	Close drilling	Sq. ft.	0 45	161,140	72,510	
	Unwatering	....	....	....	547,400	2,028,850
(f) Below Montreal Lock	Excavation—Dry rock	Cu. yd.	1 20	558,140	669,770	
	Wet rock	"	3 00	211,490	634,470	
	Wet rock, over depth	"	3 00	10,000	30,000	
	Close drilling	Sq. ft.	0 45	37,230	16,750	1,350,990
2. Dykes and walls—						
(a) Rock fill north of Dorval Island	Rock fill	Cu. yd.	0 25	718,270	179,570	179,570
(b) Lachine Wharf to Verdun Lock	Concrete	Cu. yd.	9 00	16,680	150,120	
	Concrete paving	"	11 00	54,300	597,300	
	Cribwork	"	5 00	148,200	741,000	
	Earth fill	"	0 42	1,288,570	541,200	
	Rock fill	"	0 60	108,900	65,340	
	Stripping	"	0 65	239,630	155,760	

	Trimming	Sq. yd.	0 25	146,760	36,690	
	Sodding	"	0 45	14,000	6,300	
	Unwatering				166,460	
						2,460,170
(c) Verdun Lock to Nun's Island Lock	Excavation—Earth	Cu. yd.	0 65	390,350	253,730	
	Earth fill	"	0 42	311,400	130,790	
	Earth fill	"	0 70	1,434,280	1,004,000	
	Rock fill	"	0 26	203,680	52,960	
	Trimming	Sq. yd.	0 25	111,990	28,000	
	Concrete paving	Cu. yd.	11 00	12,300	135,300	
	Stone face	"	0 65	61,440	39,940	
	Stone face on Verdun Dyke	"	0 75	78,370	58,780	
						1,703,500
(d) Nun's Island Lock to Montreal Lock	Concrete	Cu. yd.	9 00	119,210	1,072,890	
	Earth fill	"	0 65	521,690	339,100	
	Rock fill	"	0 20	193,100	38,620	
	Stone face	"	0 65	52,110	33,870	
	Trimming	Sq. yd.	0 25	52,610	13,150	
						1,497,630
(e) South end of control dam	Earth fill	Cu. yd.	1 10	4,950	5,450	
	Rock fill	"	2 20	2,750	6,050	
						11,500
3. Control works—Lake of Two Mountains	Concrete	Cu. yd.	18 00	8,450	152,100	
	Excavation—Rock	"	3 00	4,550	13,650	
	Earth fill	"	0 30	2,000	600	
	Cofferdam	Lin. ft.	50 00	4,700	235,000	
	Stop logs	M.F.B.M.	90 00	34	3,060	
	Stop log hoists	Each	5,000 00	3	15,000	
						419,410
4. Control dam at Ile au Diable	Concrete	Cu. yd.	9 00	8,270	74,430	
	Concrete	"	11 00	133,480	1,468,280	
	Foundation contingency				146,830	
	Excavation—Earth	Cu. yd.	0 65	10,120	6,580	
	Earth, trench	"	3 10	1,100	3,410	
	Rock footings	"	2 40	62,190	149,260	
	Rock trench	"	3 70	1,200	4,440	
	Sheeting and bracing	M.F.B.M.	110 00	27	2,970	
	Reinforcing steel	Ton	100 00	50	5,000	
	Superstructure and gates				1,684,700	
	Unwatering				1,559,250	
						5,105,150
5. Guard gate, entrance piers and weir	Concrete	Cu. yd.	9 00	50,390	453,510	
	Concrete	"	11 00	2,970	32,670	
	Foundation contingency				3,270	
	Cribwork	Cu. yd.	5 00	6,430	32,150	
	Excavation—Rock	"	1 20	15,620	18,740	
	Rock footings	"	1 80	1,630	2,930	
Carried forward						27,582,970

TABLE No. 30—LACHINE SECTION—RECOMMENDED PROJECT—NAVIGATION ALONE—*Contiuued*

See Plates Nos. 62—64

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						27,582,970
5. Guard gate entrance, etc.—*Con.*	Excavation—Rock trench	Cu. yd.	3 70	370	1,370	
	Earth trench	"	3 10	610	1,890	
	Sheeting—Bracing	M.F.B.M.	110 00	11	1,210	
	Close drilling	Sq. ft.	0 45	3,360	1,510	
	Lock gates, operating machinery, etc.				265,000	
	Sluice gates, hoists, etc				33,800	
						848,050
6. Verdun Lock, entrance piers and weir	Concrete	Cu. yd.	9 00	206,830	1,861,470	
	Concrete	"	11 00	8,360	91,960	
	Foundation contingency				9,200	
	Concrete paving	Cu. yd.	11 00	3,450	37,950	
	Stone face on bank	"	0 65	15,370	9,990	
	Excavation—Earth	"	0 65	568,680	369,640	
	Earth trench	"	3 10	4,620	14,320	
	Rock	"	1 20	134,580	161,500	
	Rock footings	"	1 80	5,340	9,610	
	Rock trench	"	3 70	410	1,520	
	Close drilling	Sq. ft.	0 45	91,760	41,290	
	Sheeting and bracing	M.F.B.M.	110 00	59	6,490	
	Lock gates and operating machinery				641,500	
	Lock valves and operating machinery				100,000	
	Sluice gates, hoists, etc				30,800	
	Fenders, capstans, lighting equipment, etc				196,700	
	Emergency lock gate				175,000	
	Unwatering				769,580	
						4,528,520
7. Nun's Island Lock, entrance piers and weir	Concrete	Cu. yd.	9 00	147,860	1,330,740	
	Concrete	"	11 00	4,710	51,810	
	Foundation contingency				5,180	
	Excavation—Earth	Cu. yd.	0 65	20,870	13,570	
	Earth trench	"	3 10	60	190	
	Rock	"	1 20	190,610	228,730	
	Rock footings	"	1 80	1,740	3,130	
	Rock trench	"	3 70	280	1,040	
	Close drilling	Sq. ft.	0 45	94,960	42,730	
	Sheeting and bracing	M.F.B.M.	110 00	2	220	
	Concrete paving	Cu. yd.	11 00	2,480	27,280	

	Lock gates and operating machinery				582,000	
	Lock valves and operating machinery				100,000	
	Sluice gates, hoists, etc				42,200	
	Fenders, capstans, lighting equipment, etc				196,700	
	Unwatering				1,095,950	3,721,470
8. Montreal Lock	Concrete	Cu. yd.	9 00	174,740	1,572,660	
	Excavation—Rock	"	1 20	285,200	342,240	
	Close drilling	Sq. ft.	0 45	139,290	62,680	
	Concrete paving	Cu. yd.	11 00	2,250	24,750	
	Lock gates and operating machinery				650,500	
	Lock valves and operating machinery				100,000	
	Fenders, capstans, lighting equipment, etc				196,700	
	Unwatering				88,550	3,038,080
9. Culverts under canal for Montreal aqueduct	Concrete	Cu. yd.	11 00	51,050	561,550	
	Excavation—Earth	"	0 65	32,200	20,930	
	Earth trench	"	3 10	13,560	42,040	
	Rock	"	1 20	22,600	27,120	
	Rock trench	"	3 70	840	3,110	
	Removal concrete walls	"	1 60	1,800	2,880	
	Sheeting and bracing	M ft. b.m.	110 00	240	26,400	
	Close drilling	Sq. ft.	0 45	13,800	6,210	
	Raising headworks, present aqueduct				15,600	
	Unwatering				52,090	757,930
10. Subway above Verdun lock	Concrete	Cu. yd.	11 00	14,720	161,920	
	Macadam	Sq. yd.	2 00	7,480	14,960	
	Excavation—Earth	Cu. yd.	0 65	79,450	51,640	
	Rock	"	1 20	47,100	56,520	
	Rock trench	"	3 70	230	850	
	Close drilling	Sq. ft.	0 45	28,070	12,630	
	Pumping equipment				5,000	303,520
11. Culverts at west end of Victoria Bridge	Concrete	Cu. yd.	11 00	36,660	403,260	
	Excavation—Earth	"	0 65	89,250	58,000	
	Earth trench	"	3 10	8,900	27,600	
	Rock	"	1 20	33,110	39,730	
	Rock	"	1 80	9,200	16,560	
	Rock trench	"	3 70	940	3,480	
	Close drilling	Sq. ft.	0 45	51,560	23,200	
	Sheeting and bracing	M ft. b.m.	110 00	300	33,000	
	Girders, etc., for maintaining traffic				86,550	
	Stop logs and hoists				13,380	704,760
Carried forward						41,485,300

TABLE No. 30.—LACHINE SECTION—RECOMMENDED PROJECT—NAVIGATION ALONE—*Concluded*

See Plates Nos. 62–64

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Carried forward						41,485,300
12. Bridges:—						
(a) C.P. Ry. Vertical lift at Lachine	Substructure				224,000	
	Superstructure				536,740	
						760,740
(b) Victoria bridge	Substructure				200,000	
	Superstructure				957,470	
						1,157,470
13. Removal of Lachine hydraulic plant					240,000	
						240,000
14. Water supply to Verdun and Westmount	5 ft. diam. pipe	lin. ft.	20 00	4,400	88,000	
	6 ft. diam. pipe	"	25 00	7,300	182,500	
						270,500
15. Highway changes	First class roads	lin. ft.	8 00	5,300	42,400	
	Macadam	Sq. yd.	2 00	38,900	77,800	
						120,200
16. Property damages—						
(a) North Shore	Local water supply below Lachine Bridge				20,000	
	Right-of-Way—Lands				1,363,000	
	Improvements				1,443,170	
						2,826,170
(b) South Shore	Right of Way—Lands				112,960	
	Improvements				23,860	
						136,820
17. Canal office and lighting	Office				10,000	
	Lighting				100,000	
						110,000
						47,107,200
18. Engineering and contingencies	12½%					5,892,800
19. Total						$ 53,000,000
20. If the Control Dam to raise the low water level of Lake St. Louis is not included, the total cost for improvement for navigation alone becomes						$ 50,848,000

Item and Description	Classification	Unit	Rate	Saving if Navigation channels made 23 ft. deep originally		Additional Cost if navigation channels made 27 ft. deep originally		Cost of Future enlargement from 25 ft. to 30 ft. depth	
				Quantity	Amount	Quantity	Amount	Quantity	Amount
					$		$		$
21. Deep water in Lake St. Louis to Lachine wharf.	Excavation—Earth	Cu. yd.	0 65	571,530	371,490	678,960	441,320	1,671,000	1,086,150
	Earth overdepth	"	0 65					333,700	216,910
	Wet rock	"	3 00	60,010	180,030	37,150	111,450	113,630	340,890
	Wet rock overdepth	"	3 00					21,480	64,440
	Wet rock	"	4 25	108,950	463,040	139,510	592,920	357,300	1,518,530
	Wet rock overdepth	"	4 25					80,810	343,440
22. Lachine wharf to Verdun lock	Excavation—Earth	Cu. yd.	0 65	123,580	80,270	76,570	49,770	172,650	112,220
	Dry rock	"	1 20	224,590	269,510	274,350	329,220		
	Dry rock	"	1 60	17,000	27,200	15,660	25,060		
	Wet rock	"	3 00	94,920	284,760	98,900	296,700	842,570	2,527,710
	Wet rock	"	4 25	31,640	134,470	32,980	140,170	68,860	292,650
	Wet rock overdepth	"	3 00					135,010	405,030
	Wet rock overdepth	"	4 25					93,040	395,420
23. Verdun lock to Nun's Island lock	Excavation—Earth	Cu. yd.	0 65	118,260	76,870	194,200	126,230	319,800	207,870
	Earth overdepth	"	0 65					31,110	20,220
	Dry rock	"	1 20	107,990	129,590	86,990	104,390		
	Wet rock overdepth	"	3 00					89,480	268,440
24. Nun's Island lock to Montreal lock	Excavation—Dry rock	Cu. yd.	1 20	126,450	151,740	135,200	162,240		
	Wet rock	"	3 00					336,740	1,010,220
	Wet rock overdepth	"	3 00					65,950	197,850
25. Below Montreal lock	Excavation—Dry rock	Cu. yd.	1 20	39,320	47,180	40,130	48,160		
	Wet rock	"	3 00	16,980	50,940	31,830	95,490	178,090	534,270
	Wet rock overdepth	"	3 00					13,330	39,990
					2,267,090		2,523,120		10,657,830
26. Engineering and contingencies	12½% approximately				249,910		315,880		1,903,170
27. Totals					2,517,000		2,839,000		12,561,000

TABLE No. 31.—LACHINE SECTION—NAVIGATION ALONE—RECOMMENDED PROJECT

For details—see Table No. 30

Lake of Two Mountains control	$ 419,410	
Navigation works—Lake St. Louis to Montreal	40,809,060	
Control dam	5,878,730	
Engineering and contingencies—12½ per cent	5,892,800	
		$ 53,000,000
Saving if navigation channels made 23 ft. deep originally		$ 2,517,000
Additional cost if navigation channels made 27 ft. deep originally		2,839,000
Cost of future enlargement from 25 ft. depth to 30 ft. depth		12,561,000

TABLE No. 32.—LACHINE SECTION—POWER DEVELOPMENT—SUBSEQUENT TO NAVIGATION AS IN RECOMMENDED PROJECT

See Plates Nos. 65-66

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
1ST STAGE—POWER FROM CANAL ON SOUTH SHORE—						
Total installed capacity, 435,000 h.p.						
(A) SUBSTRUCTURE, HEAD AND TAIL-RACE EXCAVATION, ETC.—						
1. Channel excavation—						
(a) In Lake St. Louis above control weir	Excavation—Earth	Cu. yd.	0 65	3,154,600	2,050,490	
	Earth over depth	"	0 65	400,000	260,000	
	Dry rock	"	1 60	1,407,800	2,252,480	
	Unwatering				578,160	
						5,141,130
(b) Control weir to power house	Excavation—Dry rock	Cu. yd.	1 20	1,284,000	1,540,800	
	Dry rock	"	1 60	12,633,100	20,212,960	
	Earth	"	0 65	3,198,780	2,079,210	
						23,832,970
(c) Power house tailrace	Excavation—Earth	Cu. yd.	0 65	1,142,800	742,820	
	Dry rock	"	1 60	762,000	1,219,200	
	Wet rock	"	4 25	154,170	655,220	
	Wet rock over depth	"	4 25	72,000	306,000	
	Earth	"	0 65	113,000	73,450	
						2,996,690
2. Control weir at Caughnawaga	Concrete	Cu. yd.	9 00	3,300	29,700	
	Concrete	"	11 00	42,510	467,610	
	Foundation contingency				46,760	
	Excavation—Rock footings	Cu. yd.	2 40	18,530	44,470	
	Gates, hoists, etc				289,900	
						878,440
3. Dykes and walls—Control weir to power house	Concrete	Cu. yd.	9 00	656,770	5,910,930	
	Concrete	"	11 00	191,000	2,101,000	
	Foundation contingency				210,100	
	Excavation—Rock footings	Cu. yd.	2 40	68,000	163,200	
	Earth fill	"	0 60	370,260	222,160	
	Rock fill	"	0 60	138,760	83,260	
	Stripping	"	0 65	68,300	44,400	
	Unwatering				1,085,600	
						9,820,650
4. Ice sluices at power house	Concrete	Cu. yd.	9 00	8,320	74,880	
	Concrete	"	11 00	17,360	190,960	
	Foundation contingency				19,100	
	Excavation—Rock footings	Cu. yd.	2 40	6,200	14,880	
	Rock trench	"	4 10	500	2,050	
	Earth trench	"	3 10	490	1,520	
Carried forward						42,669,880

TABLE No. 32—LACHINE SECTION—POWER DEVELOPMENT—SUBSEQUENT TO NAVIGATION AS IN RECOMMENDED PROJECT—*Continued*

See Plates Nos. 65-66

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
Brought forward						42,669,880
1ST STAGE, ETC.—*Con.*						
(A) SUBSTRUCTURE, HEAD AND TAIL-RACE EXCAVATION, ETC.—*Con.*						
4. Ice sluices at power house—*Con.*	Sheeting and bracing	M.F.B.M.	110 00	10	1,100	
	Gates, hoists, etc				94,900	399,390
5. Transforming movable dam in river with cribs and stop logs	Cribwork	Cu. yd.	5 00	24,930	124,650	
	Stop logs	M.F.B.M.	110·00	676	74,360	
	Hoists, etc				50,000	249,010
6. Revision at C.P.Rly.—Bridge at Caughnawaga	Bridge—Substructure				150,000	
	Superstructure				256,000	
	Railway relocation				242,420	
	Subway				50,000	698,420
7. Power house substructure	Concrete	Cu. yd.	14 00	370,260	5,183,640	
	Gates and racks				1,353,820	
	Unwatering				961,400	7,498,860
8. Roads and property damages	Roads—New	Lin. ft.	8 00	18,000	144,000	
	Macadam on banks	Sq. yd.	·2 00	10,220	20,440	
	Property—Right of way				215,280	
	Improvements				1,624,200	2,003,920
						53,519,480
9. Engineering and contingencies	12½ per cent					6,689,520
10. Total						60,209,000
(B) MACHINERY AND SUPERSTRUCTURE—						
11. Machinery and superstructure	Generators and turbines, 19-22,900 h.p. units				12,304,020	
	Switching				2,783,310	
	Cranes and service units				258,680	
	Superstructure				3,354,800	18,700,810
12. Engineering and contingencies	12½ per cent					2,337,190
13. Total						21,038,000

2ND STAGE—POWER IN RIVER AT FOOT OF LACHINE RAPIDS—Total installed capacity, 488,000 h.p.						
(A) SUBSTRUCTURE, HEAD AND TAIL-RACE EXCAVATION, ETC.—						
14. Removal of movable dams and cribs	Excavation	Cu. yd.	4 25	106,630	453,180	453,180
15. Dam	Concrete	Cu. yd.	9 00	31,420	282,780	
	Concrete	"	11 00	275,450	3,029,950	
	Foundation contingency				303,000	
	Excavation—Rock footings	Cu. yd.	2 40	68,930	165,430	
	Rock trench	"	4 10	3,470	14,230	
	Earth	"	0 65	536,620	348,800	
	Earth fill	"	0 60	252,520	151,510	
	Rock fill	"	0 60	93,470	56,280	
	Stripping	"	0 65	44,460	28,900	
	Unwatering				1,634,720	
	Gates, hoists, etc				689,000	6,704,600
16. Power house substructure	Concrete	Cu. yd.	14 00	368,650	5,161,100	
	Gates and racks				1,353,820	
	Excavation—Earth	Cu. yd.	0 65	1,235,200	802,880	
	Dry rock	"	1 60	762,000	1,219,200	
	Wet rock	"	4 25	278,000	1,181,500	
	Wet rock, over depth	"	4 25	70,000	297,500	
	Earth over depth	"	0 65	111,000	72,150	
	Unwatering				1,357,000	11,445,150
						18,602,930
17. Engineering and contingencies	12½ per cent					2,325,070
18. Total						20,928,000
(B) MACHINERY AND SUPERSTRUCTURE—						
19. Machinery and superstructure	Generators and turbines—19–25,700 h.p. units				12,304,020	
	Switching				2,783,310	
	Cranes and service units				258,680	
	Superstructure				3,354,800	18,700,810
20. Engineering and contingencies	12½ per cent					2,337,190
21. Total						21,038,000

45827—25

TABLE No. 32—LACHINE SECTION—POWER DEVELOPMENT—SUBSEQUENT TO NAVIGATION AS IN RECOMMENDED PROJECT—*Concluded*

SUMMARY

		$	$
1ST STAGE—Installed capacity 435,000 h.p.—			
Substructure, head and tail-race excavation, etc.	Item No. 10	60,209,000	
Machinery and superstructure	" 13	21,038,000	
			81,247,000
2ND STAGE—Installed capacity 488,000 h.p.—			
Substructure, head and tail-race excavation, etc.	Item No. 18	20,928,000	
Machinery and superstructure	" 21	21,038,000	
			41,966,000
TOTAL—Total installed capacity 923,000 h.p.			123,213,000
Cost of 1st stage of development if no control dam is built for navigation			88,131,000

TABLE No. 33.—LACHINE SECTION—POWER SUBSEQUENT TO NAVIGATION

For details—see Table No. 32

1st Stage—Power house on south shore		391,000 h.p.
2nd Stage—Power house in river		422,000 h.p.
1st Stage—		
Substructure, head and tail-race excavation	$ 60,209,000	
Machinery and superstructure	21,038,000	
		$ 81,247,000
2nd Stage—		
Substructure, head and tail-race excavation	$ 20,928,000	
Machinery and superstructure	21,038,000	
		41,966,000
Total		$123,213,000

Power House Installations

1st Stage—19–22,900 h.p. units (31 ft. head)	435,000 h.p.
2nd Stage—19–25,700 h.p. units (33·5 ft. head)	488,000 h.p.
Total	923,000 h.p.

TABLE No. 34—LACHINE SECTION—TABLE SHOWING OVER ALL COST OF POWER DEVELOPMENT SUBSEQUENT TO NAVIGATION

Interest during construction and marketing period, 5 per cent.
Power marketed at 75,000 h.p. per year.
Construction program planned for expenditure of $10,000,000 per year.

—	1st cost	Half construction period	Half market period	Interest	
1st Stage—391,000 h.p.	60,209,000 21,038,000	3·01	2·60	0·315	18,980,000
2nd Stage—422,000 h.p.	20,928,000 21,038,000	1·05	2·81	0·209	4,370,000
	$123,213,000				$ 23,350,000
Add first cost					123,213,000
Total					$146,563,000

TABLE No. 35.—LACHINE SECTION—NAVIGATION ALONE WITHOUT CONTROL DAM

Item and description	Classification	Unit	Rate	Quantity	Amount	Total
			$ cts.		$	$
1. Channel excavation—						
(a) Deep water in Lake St. Louis to Lachine Wharf	Excavation—Earth	Cu. yd.	0 65	5,399,700	3,509,810	
	Earth, over depth	"	0 65	333,700	216,910	
	Wet rock	"	3 00	407,730	1,223,190	
	Wet rock over depth	"	3 00	21,480	64,440	
	Wet rock	"	4 25	578,800	2,459,900	
	Wet rock over depth	"	4 25	80,810	343,440	7,817,690
(b) Lachine Wharf to Verdun Lock	Excavation—Earth	Cu. yd.	0 65	6,080,630	3,952,410	
	Dry rock	"	1 20	1,441,040	1,729,250	
	Dry rock	"	1 60	141,600	226,560	
	Wet rock	"	3 00	513,860	1,541,580	
	Wet rock	"	4 25	140,840	598,570	
	Wet rock over depth	"	4 25	62,300	264,770	
	Close drilling	Sq. ft.	0 45	79,300	35,690	8,348,830
(c) Verdun Lock to below Montreal Lock	See Table No. 30—Item No. 1 (d), (e), (f)					4,123,140
2. Dikes and walls—						
(a) Rock fill north of Dorval Island	Rock fill	Cu. yd.	0 25	718,270	179,570	179,570
(b) Lachine Wharf to Verdun Lock	Concrete	Cu. yd.	9 00	15,560	140,040	
	Concrete paving	"	11 00	54,300	597,300	
	Cribwork	"	5 00	133,880	669,400	
	Earth fill	"	0 42	1,288,570	541,200	
	Rock fill	"	0 60	108,900	65,340	
	Stripping	"	0 65	239,630	155,760	
	Trimming	Sq. yd.	0 25	146,760	36,690	
	Sodding	"	0 45	14,000	6,300	
	Unwatering				166,460	2,378,490
(c) Verdun Lock to Montreal Lock	See Table No. 30—Item No. 2 (c) (d)					3,201,130
3. Guard gate, entrance piers and weir	" " 5					848,050
4. Verdun Lock, Nun's Island Lock, and Montreal Lock	" " 6, 7, 8					11,288,070
5. Culverts under Canal for Montreal Aqueduct	" " 9					757,930
6. Subway above Verdun Lock	" " 10					303,520
7. Culverts at west end of Victoria Bridge	" " 11					704,760
8. Bridges	" " 12					1,918,210
9. Water supply to Verdun and Westmount	See Table No. 30—Item No. 14					270,500
10. Highway changes	" " 15					120,200
11. Property damages	" " 16 (a)					2,826,170
12. Canal office and lighting	" " 17					110,000
						45,196,260

13. Engineering and contingencies	12½ per cent	5,651,740
14. Total		50,848,000
Cost of future enlargement from 25 feet depth to 30 feet depth— (a) Prior to power development		11,388,000
(b) Subsequent to power development		3,774,000

TABLE 36—INTERNATIONAL RAPIDS SECTION—POWER HOUSE INSTALLATIONS

Site		Heads		Flow excl. of spares c.f.s.	Unit Rating				Installation							
									Units No. (a)	H	H.P.	c.f.s.	Total		Service Units	
		W.L's	H		H	H.P.	c.f.s.						H	H.P.	No.	H.P.
Ogden Isd. 224	N.S.	244–227	17	230,300b	16	5,190	3,240	P	70+3	17	5,570	3,290	17	406,610	2	1,000
	N.W.	240–228	12	211,400						12	3,620	3,020	12	264,260	3	1,500
Barnhart Isd. 224	N.S.	224–157	67	252,000	63	43,520	6,800	F	36+2	67	47,600	7,000	67	1,808,800	6	1,500
	N.W.	224–161	63	245,000b						63	43,520	6,800	63	1,653,760		
	Max. O.	226–155	71													
	Min. O.	224–163	61													
Crysler Isd. 217	N.S.	243·5–219	24·5	231,200	20	12,900	6,450	P	34+2	24·5	16,600	6,800	24·5	597,600	6	1,200
	N.W.	239·5–220	19·5	218,000b						19·5	12,500	6,420	19·5	450,000		
	Max. O	244–128	26													
	Min. O	237–222	15													
Barnhart Isd. 217	N.S.	217–157	60	245,820	60	44,500	7,300	F	34+2	60	44,500	7,300	60	1,602,000	6	1,500
	N.W.	217–161	56	240,000b						56	40,200	7,050	56	1,447,200		
	Max. O	219–155	64													
	Min. O	217–163	54													
Barnhart Isd. 238	N.S.	238–167	81	259,980	75	45,100	5,950	F	42+2	81	50,600	6,190	81	2,226,400	6	1,500
	N.W.	236–161	75	250,000b						75	45,100	5,950	75	1,984,400		
	Max. O	239–155	84													
	Min. O															
Barnhart Isd. 242	N.S.	242–157	85	266,280	75	45,100	5,950	F	42+2	85	54,400	6,340	85	2,393,600	6	1,500
	N.W.	236–161	75	250,000b						75	45,100	5,950	75	1,984,400		
	Max. O	243–155	88													
	Min. O	235–163	72													

NOTE.—(b) Denotes flow on which installation is based. (a) Last figure equals number of spares.
N.S.—Normal Summer. N.W.—Normal Winter. Max. O.—Maximum Operating. Min. O.—Minimum Operating. P.—Propellor wheel.
F.—Francis wheel.

TABLE 37.—SOULANGES SECTION—POWER HOUSE INSTALLATIONS

Site	Heads		Flow excl. of spares	Unit Rating				Installation							
								Units				Total		Service Units	
	W.L's	H	c.f.s.	H	H.P.	c.f.s.		No. (a)	H	H.P.	c.f.s.	H	H.P.	No.	H.P.
RECOMMENDED PROJECT—															
1. Ile aux Vaches.... N.S.	149–127	22	173,300	20	13,700	6,640	P	26	22	15,550	6,800	22	404,300	5	1,200
N.W.	147–128	19	163,300						19	12,850	6,550	19	334,100		
Max. O.	150–126	24													
2. Chamberry Gully N.S.	147·5–72	75·5	66,700	75	54,000	7,000	F	10	75·5	54,500	7,020	75·5	545,000	3	1,000
N.W.	144–74	70	66,700						70·0	48,600	6,760	70·0	486,000		
Max. O.	147·5–71	76·5													
3. Cascades Isd..... N.S.	125–72	53	183,300	57	41,100	7,140	F	28	53	36,800	6,900	53	1,030,400	3	1,500
N.W.	125–74	51							51	34,800	6,750	51	974,400		
Max. O.	125–71	54													
RIVER ROUTE—CENTRE POOL EL. 115—															
1. Cedars—South Plant N.S.	148–115·5	32·5		30	22,000	7,300	P	26	32·5	24,300	7,450	32·5	631,800	3	1,500
N.W.	145–116	29	184,500						29·0	21,200	7,250	29·0	551,200		
Max. O.	149–114	35													
½ Cascades Isd...... N.S.	115–72	43		40	31,000	7,600	P	8	43	34,000	7,730	43	272,000	1	1,500
N.W.	115–74	41	61,000						41	32,100	7,640	41	256,800		
Max. O.	115–71	44													
2. Cedars—North Plant—Heads as for South Plant.....		29	55,500	30	22,000	7,300	P	8	32·5	24,300	7,450	32·5	194,400	1	1,500
									29·0	21,200	7,250		169,600		
3. ¾ Cascades Isd.—Heads as for ¼ Cascades............		41	188,900	40	31,000	7,600	P	25	43	34,000	7,730	43	850,000	3	1,500
									41	32,100	7,640	41	802,500		
RIVER ROUTE—CENTRE POOL EL. 125—															
1. Pte. à Biron...... N.S.	149–127	22	240,000	20	13,700	6,640	P	36	22	15,550	6,800	22	559,800	6	1,200
N.W.	147–128	19	235,000						19	12,850	6,550	19	462,600		
Max. O.	150–126	24													
2. Cascades Isd..... N.S.	125–72	53		57	41,100	7,140	F	38	53	36,800	6,900	53	1,398,400	4	1,500
N.W.	125–74	51	250,000						51	34,800	6,750	51	1,322,400		
Max. O.	125–71	54													
FOUR STAGE PROJECT—															
1. Melocheville...... N.S.	149·5–72	77·5		75	45,000	5,900	F	6	77·5	47,300	6,000	77·5	283,800	1	1,000
N.W.	148–74	74	33,600						74·0	44,000	5,850	74·0	264,000		
Max. O.	149·5–71	78·5													
2. Ile aux Vaches—As in 1st Stage of Recommended Project........................												22	404,300	5	1,200
												19	334,100		

3. Chamberry Gully—Heads as in Recommended Scheme...	....	....	35,000	75	54,000	7,000	F	6	75·5 70·0	54,500 48,600	7,020 6,760	75·5 70·0	327,000 291,600	2	1,000
4. Cascades Isd.—As in 3rd Stage of Recommended Project......	....	....	....	......	....	....	......	....	......	....	....	53 51	1,030,400 974,000	3	1,500

Note.—N.S.—Normal Summer. N.W.—Nornal Winter. Max. O.—Maximum Operating. (a) No. of Units including spares. P.—Propellor Wheel. F.—Francis Wheel.

TABLE 38.—LACHINE SECTION—POWER HOUSE INSTALLATIONS

Site		Heads		Flow excl. of spares c.f.s.	Unit Rating				Installation							
									Units No. (a)	H	H.P.	c.f.s.	Total		Service Units	
		W.L's	H		H	H.P.	c.f.s.						H	H.P.	No.	H.P.
Lachine—Canal......	N.S.	68-37	31	132,000	30	22,000	7,300	P	81+1	31	22,900	7,350	31	435,100	3	1,500
	N.W.	68-41	27	128,000	......	....	....	......	....	27	19,300	7,110	27	366,700		
	Max. O.	70-36	34	....	......	....	....	......	....	23	15,800	6,830	23	300,200		
	Min. O.	68-45	23													
Lachine—River.......	N.S.	70·5-37	33·5	135,000	30	22,000	7,300	P	18+1	33·5	25,700	7,500	33·5	488,300	3	1,500
	N.W.	69·5-41	28·5	130,000	......	....	....	......	....	28·5	20,600	7,200	28·5	391,400		
	Max. O.	70·5-36	34·5	....	......	....	....	......	....	23	15,800	6,830	23	300,200		
	Min. O.	68-45	23													

Note.—(a) Last figure equals number of spares. N.S.—Normal Summer. N.W.—Normal Winter. Max. O.—Maximum Operating. Min. O.—Minimum Operating. P.—Propellor Wheel.

TABLE No. 39.—ACREAGE OVERFLOWED AT MAXIMUM LEVELS BY VARIOUS ALTERNATIVE PROJECTS IN INTERNATIONAL RAPIDS SECTION

—	Single stage Project No. 1-242	Ogden Island Project No. 4-224	Crysler Island Project No. 5-217	Single stage controlled Project No. 6-238
	acres	acres	acres	acres
In Canada (Mainland)	4,952	3,258	4,471	3,493
In United States (Mainland)	11,359	4,434	5,444	7,421
On slands	5,542	4,295	3,465	5,308
Total	21,853	11,987	13,380	16,222

*TABLE NO. 40.—INTERNATIONAL RAPIDS SECTION—CRYSLER ISD.—TWO-STAGE DEVELOPMENT—217

Cost to develop power at Crysler Island and to carry navigation through to Lake St. Francis, including works necessary to raise lower pool to elevation 217 at Long Sault.

Upper Pool—		
Works solely for Navigation	8,732,000	
Works common to Navigation and Power	69,986,000	
Works primarily for Power—		
Substructures, Head and Tailrace Excavation	25,698,000	
Machinery and Superstructures	30,760,000	
		135,176,000
Lower Pool—		
Works solely for Navigation	25,618,000	
Works common to Navigation and Power—		
Permanent Works	14,180,000	
Temporary Works—		
Dam north of L. Sault Isd. including bank and Unwatering	4,750,000	
		44,548,000
Total		$179,724,000

SUBSEQUENT COST TO DEVELOP POWER AT BARNHART ISLAND

Works common to Navigation and Power	13,153,000	
Works Primarily for Power—		
Substructures, Head and Tailrace Excavation	35,519,000	
Machinery and Superstructures	43,418,000	
Total		$ 92,090,000

Grand Total—	
Total cost of development of all power in International Rapids Section by this method of Procedure	$271,479,000

*Prepared by Canadian Section. Not checked by United States Section.

APPENDIX D

RIVER LEVELS AND DISCHARGES AT AND BELOW MONTREAL

1. The manner in which regulation of outflow from lake Ontario changes water levels in Montreal harbour has been dealt with in part IV and appendix B of this report. A summary of the extent to which diversions from the Great Lakes system and from the St. Lawrence river above Montreal, lower water levels at and below Montreal has been given in the main report. This appendix gives the basic data and computations from which the conclusions were drawn.

2. To determine the effect of diversion, it is necessary to obtain the relation between gauge height and discharge at a number of points in the river. In this study, relations were first established for governing points and then relations were extended from these to other points in this River. The governing points chosen were lock 25 at Iroquois in the International Section and the upper reach at Grenville on the Ottawa river.

3. The flow of the St. Lawrence River near lock 25 has been measured by approved methods on many occasions and throughout a wide range of stage. The U.S. Lake Survey made many measurements at Point Three Points in the years 1901, 1902, 1908, 1911, 1913 and 1914. The Public Works Department duplicated most of this work in the years 1918, 1919 and 1920, and in recent years the Canadian Department of Railways and Canals extended and checked this work by meterings above Iroquois Point. From all these measurements a reliable relation between discharge and gauge height at Lock 25 has been established, (plates Nos. 1 and 2). By simultaneous gauge readings this relation has been extended to all gauges upstream to Lake Ontario and downstream to Lock 21, at the head of the Long Sault Rapids. By use of rating stations on the St. Regis and Grass rivers, established years ago, and by records on other streams the relation between discharge and stage at the outlet of lake St. Francis has also been derived.

4. A relation between discharge and stage at Grenville on the Ottawa river has been established (plate No. 3), in part from measurements made above and below that point by the Public Works Department in the years 1907-18, in part by the measurements made by the Department of Railways and Canals and in part by the use of weir formulae applied to the spillway dam at Carillon. Stage relation diagrams extending over a wide range have have also been established from meterings by the Public Works Department for the several outlets of Lake of Two Mountains (plate Nos. 4 and 5). They have been closely checked with discharge at Grenville during periods of low precipitation.

5. By selection of periods during which local precipitation was low and during which no high wind occurred and by use of gauge discharge relations in tributary streams, records of flow in all streams leading to the foot of Lake St. Louis were accumulated and by correction for local storage, a relation was derived for lock No. 5, Lachine (plates 6, 7 and 8). The relation established in this way was checked by meterings opposite the mouth of the Montreal Aqueduct a few miles below Lock No. 5. The direct measurements made below Lachine do not cover a wide range of stage but check discharge relations derived by the method above described.

6. In establishing the gauge discharge relations at Lock 5, Lachine, two indirect methods were used.

7. In the first method, the total flow for selected storm-free periods for Lock 25 on the St. Lawrence and for Upper Grenville on the Ottawa was read off adopted curves. To this was added the run-off of the drainage area from Lock 25 to Lock 5 on the St. Lawrence and from Upper Grenville to Upper St. Annes on the Ottawa. From the total discharge thus obtained the flow through the Mille Iles and Des Prairie rivers, as read from curves, was deducted. This gave the discharge in the main river past Lachine. During these periods, the run-off from this drainage area was approximated from the rate of flow per unit of drainage area in near-by rivers where the area and outflow were available from established ratings.

8. In the second method the total flow past lock 5, Lachine, was derived by adding the discharge of the St. Lawrence west of lock 25 to that of the two outlets of Lake of Two Mountains which lead into lake St. Louis and adding to this again, the run-off of the drainage area between lock 25 and lock 5 Lachine, derived proportionally from other local streams as in the first case described. The flow out of Lake of Two Mountains in this case was taken as independent of the level of Lake St. Louis.

9. The results obtained by the two methods were found to be in close agreement. Those established by the latter method were used in the discharge gauge relation adopted for lock No. 5, Lachine. Table No. 1 showing the computations for the relation adopted for the period 1904 to date is attached to this Appendix. The discharge gauge relation is shown on Plate No. 7.

10. The discharge gauge relation for the period 1860 to 1877 is not based on extensive data and is probably not as reliable as that for the later period. In some cases the determinations made were somewhat round-about due to gauge records at all stations not being complete. Computations for this period are shown on Table No. 2 and the discharge is shown on Plate No. 6.

11. The discharge relation for the period of 1884 to 1895 was derived from continuous comparisons of a number of gauge readings and known changes in the outlet of Lake St. Louis, and is shown on Plate No. 8.

12. A discharge gauge relation for Pointe Ste. Clair gauge on lake St. Louis is also attached to this appendix, plate No. 9. It has been derived by continuous comparison of the readings at this point with those at lock No. 5, Lachine. The readings of the gauge at lock No. 5, Lachine, fluctuate due to changes in flow in the canal while the readings of the gauge at Pointe St. Claire are not subject to such changes.

13. Gauge relations in Montreal harbour and below show that water levels as far up as the foot of the Lachine canal vary with the spring and neap tides as well as with the relative flow in the Ottawa and St. Lawrence rivers and changes of wind. Accordingly, only neap tide weeks and periods of little wind were used in compiling data for the determination of discharge stage relations at and below Montreal.

14. It is not possible to derive a simple discharge relation for the water level in Montreal harbour, due to the back-water effects of the flow from the Mille Iles, Des Prairies and other rivers which enter the main river below Montreal. The stage of the Ottawa and other rivers entering the St. Lawrence is often high when that of the St. Lawrence at Lachine is relatively low. Meterings of the St. Lawrence below Montreal do not give much information because of the interference of the tide and the sensitiveness of the river to changes of the wind. The back-water effect of the inflow from the rivers downstream from the Des Prairies outlet of the Ottawa river is noticeable in Montreal harbour but its magnitude is small, except when the lower tributaries are in flood.

15. In order to develop discharge stage relations that would enable the effect of given diversions to be dealt with, a series of discharge stage relations were derived at a number of points at and below Montreal from diagrams for Lachine, plate No. 8, and Pointe Claire, plate No. 9, based on periods during which the discharges down the Mille Iles and Des Prairies rivers were constant.

16. In the preparation of diagrams a series of periods during which the water levels at Upper St. Annes varied between 69.6 and 70.0, 70.0 and 70.4, 70.4 and 70.8, etc., were grouped together and a diagram of discharges and stages for lock No. 1, Montreal harbour produced for each series. The plotted results in two of the series used are attached to this Appendix, plate No. 11, along with the table (No. 3) from which they were obtained. The result of all the computations, plate No. 10, shows that, as the general discharge stage relations are expressed by straight lines, the amount of change in stage for a given change in flow is constant, regardless of the stage of the river at Lock No. 1, Montreal. With a rise or fall of 1 foot on the Lock 1 gauge, the level of Lake of Two Mountains remaining constant, the increase or decrease of flow in the St. Lawrence may be taken as 23,000 cubic feet per second. Conversely, if the flow in the St. Lawrence be reduced by 23,000 cubic feet per second, the lowering of the water level at Lock No. 1 will be 1 foot. By proportion, a reduction of flow of 8,500 cubic feet per second (which is the present authorized diversion at Chicago) lowers the water level in the harbour to the extent of 0.37 feet.

17. The determination of the discharge stage relation at Varennes is simpler than the determination of this relation in Montreal harbour, because the flow past the point in this case is the factor which largely governs in the relation. However, the volume of inflow from rivers below Varennes still influences stages at Varennes. The determination of the precise manner in which changes in flow in each stream affects the stage at Varennes would be a long and futile task as the number of points where water enters is very large and the effect of many is so small that they cannot be detected in gauge relations which are also affected by tide and wind.

18. The best that can be done is to approximate from the Chezy formulæ the back-water effect of one or two of the larger rivers and assume that a certain percentage of the flow in these would produce the actual stages found if it were added to the flow past the point.

19. In this way, the diagram, plate No. 12, attached to this appendix, was developed. The discharge taken as governing the relation is: That of the main river, derived from the pointe Claire gauge, plus the discharge for the Mille Iles and Des Prairies rivers derived from the Upper St. Annes gauge, plus that estimated for the tributary area between these gauges and Varennes, plus one-half the flow of the Richelieu river and one-third of the St. Maurice to cover an amount that would produce the same effects at the gauge as that which does actually enter the St. Lawrence below Varennes. The inflow from the tributary area between lake St. Louis and Lake of Two Mountains and Varennes was taken as a proportion of the St. Maurice river. The computations are shown on Table No. 4.

20. The discharge stage relation for Sorel, plate No. 13, was obtained by taking the governing flow as that of the main river plus that of the Mille Iles, Des Prairies and Richelieu rivers, plus that of the drainage area between Sorel and the outlets of lake St. Louis, Lake of Two Mountains and lake Champlain, plus the flow of the St. Francis river and a portion of the flow of the St. Maurice. Computations are included in Table No. 4.

21. The curves of discharge stage relation shown on plates Nos. 12 and 13, are so drawn in the lower range as to be parallel to lines connecting series of observations in which the flow of the St. Maurice stood constant. In this way the slope of the lower part of the curve is more accurately shown than might appear from the points on the diagram.

22. From table No. 4, it may be seen that at low stages a change in flow of 24,500 cubic feet per second causes a change of stage of 1 foot at Varennes, or a diminution of 8,500 cubic feet per second in flow lowers the level at that point to the extent of 0.35 foot, and at Sorel, 31,000 cubic feet per second represents a change of stage of 1 foot or a diminution in flow of 8,500 cubic feet per second causes a lowering in water level of 0.28 foot.

23. In a way similar to that above described, the effect of a reduction in flow of 8,500 cubic feet per second at Batiscan was found to be equivalent to 0.24 foot of stage. At points further down, the effect of the diversion was taken as proportional to the relative change in level as shown on published charts.

24. The effect of a diminution in flow of 8,500 cubic feet per second at various points in the lower St. Lawrence may be summarized as follows:—

	Feet
Montreal Harbour	0.37
Varennes	0.35
Sorel	0.28
Batiscan	0.24
Lotbiniere	0.24
Pt. Platon	0.17
Quebec	0.03

25. *Compensation.* The losses in stage summarized in the last paragraph can be restored by dredging Montreal harbour and the river channel to a greater depth and lowering the foundations of docks and wharves in the harbour accordingly.

The amount of dredging required would be the amount of losses shown with an addition of about 15 per cent in the case of Montreal harbour and an average of 6 per cent in the channel between Varennes and Quebec, this additional amount being necessary to compensate for the further recession resulting from this dredging. The probability of dredging for compensation being done as a special work is not entertained as this would be an expensive undertaking. It seems reasonable to assume that it would be incorporated in a general program and the rates used in the estimate of cost are based on this assumption. The programs of the past have been for deepening from 27½ to 30 feet and a later program, now about half completed, is for deepening from 30 to 35 feet. The following table shows the yardage involved in deepening the channel to the extent of 5 feet from Montreal to deep water above Quebec, with an estimate of the further quantities to be removed to compensate for a diversion from the river above Montreal of 8,500 cubic feet per second.

	Cubic Yards To excavate from 30 to 35 feet	Cubic Yards Required to compensate
Montreal to Sorel	16,571,961	1,330,000
Sorel to Bastiscan	24,938,875	1,380,000
Batiscan to Lotbiniere	6,595,441	364,000
Lotbiniere to St. Augustin	2,601,766	94,000
Total		3,168,000
3,168,000 cu. yds. at 42.5 cents per cu. yd.		$1,346,400
Plant, shops, surveys, etc., average, proportional cost since beginning of works, 60 per cent		807,600
Total		$2,154,000

26. *Dredging Montreal Harbour.* The dredged area in Montreal harbour at the present time is about 18,364,000 square feet in earth and 5,540,000 square feet in shale rock.

A loss in depth of about 1.15 feet has occurred in this harbour since 1899, from causes other than the Chicago diversion. A deepening of the whole harbour to the extent of 3 feet probably represents what will be done as regards some parts and what has already been done in others.

The estimated cost of such deepening over and above what was and is required to preserve original works is as follows:—

Shale rock dredging 5,540,000 x 3/27= 616,000 c.y. at \$3.50	\$2,160,000
Earth dredging .. 18,364,000 x 3/27=2,040,000 c.y. at 1.00	2,040,000
The cost, total	\$4,200,000
Add for engineering and contingencies 10%	420,000
Total	\$4,620,000

Of this 3 feet, the portion chargeable to the Chicago Diversion is 0.37 foot, increased by 15%=0.425 foot. The amount chargeable to Chicago Diversion therefor will be $\frac{0.425}{3}$ x 4,620,000=\$654,000.

27. *Piers and Dock Walls.* To restore all losses due to lowered water levels in Montreal is a large undertaking. There are at present 46,000 lineal feet of high dock wall, all of which are solid retaining crib construction, below the bottom level of which excavation cannot be carried without danger of collapse. Some of it is founded on shale rock and some of it has only an earth foundation. The dock walls which were built before 1901 are all of timber construction throughout, while those recently built are timber in the lower 30 feet of their height, and concrete above. The upper 24 feet of the older work is subject to decay, and reconstruction of this will be required before long.

28. The estimate prepared by the Canadian section (see paragraph 214, main report) assumes that the newer docks were built deep enough to care for the loss in depth due to the diversion at Chicago and that the older docks will require to be rebuilt to a greater depth in the near future.

The cost of reconstruction of docks for an increase in depth of 3 feet will be:—

30 feet and over, 30,720 lin. feet, 1,164,000 c.y. at \$7.00	\$ 8,148,000
27 feet and over, 12,300 lin. feet, 410,000 c.y. at \$7.00	2,870,000
20 feet and over, 3,244 lin. feet, 58,000 c.y. at \$7.00	406,000
Total	\$11,424,000
Add engineering and contingencies, 10%	1,143,000
Total	\$12,567,000

As in the case of harbour dredging, the portion chargeable to Chicago diversion is in the ratio of 0.425 feet to 3.0 feet, which is, say \$1,800,000.

29. SUMMARY. The total estimated cost of increasing the depth in Montreal harbour and the St. Lawrence ship channel, to compensate for a diversion of 8,500 cubic feet per second, will be as follows:—

Dredging ship channel, Montreal to St. Augustine	\$2,154,000
Dredging, Montreal harbour	654,000
Reconstruction of dock walls, etc.	1,800,000
Grand total	\$4,608,000

Adopted by the Board, June 2, 1927.

TABLE NO. 1.—SHOWING DERIVATION OF DISCHARGE STAGE RELATION FOR LOCK 5, LACHINE GAUGE. PERIOD 1904 TO DATE

Date	S. Nation R. Disch. (Drainage A.=1,436 S.M.)	Oswegatchie R. Disch. (Drainage A.=1,580 S.M.)	Paquette R. Disch. (Drainage A.=1,170 S.M.)	St. Regis R. Disch. (Drainage A.=621 S.M.)		Total Drainage Area	Total Discharge	Disch. of Drainage A.L. 25–L.5= 5,800 S.M.Q.=5,800 x Col. (8) / Col. (7)	Disch. of Drainage A, Grenville to St. Annes=1,186 S.M. + That shown in Col. (9) Q=6,986 x Col. 8 / Col. 7	Lock 25 Disch.	Des Prairies R. Disch.	Grenville Disch.	Upper St. Annes (Vaudreuil) Disch.	Lock 5, Lachine W.Elev.	Total Disch. Cols. (10) + (11) + (13) − (12)	Total Disch. Cols. (9) + (11) +14)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
May 1913.	700	992	1,540	829	....	4,807	4,061	4,900	5,890	281,600	90,500	157,000	85,000	70·48	353,990	371,500
July 1913.	120	600	659	325	....	4,807	1,704	2,060	2,480	278,300	31,000	45,500	16,500	68·22	295,280	296,860
Aug. 1913.	120	460	359	258	....	4,807	1,197	1,440	1,740	265,200	23,000	30,000	9,200	67·55	273,940	275,840
Sept. 1913.	100	408	180	233	....	4,807	921	1,110	1,340	252,500	20,300	26,000	7,100	67·20	259,540	260,710
7–16 Oct. 1913.	100	600	150	450	....	4,807	1,300	1,570	1,890	244,700	20,400	23,200	7,400	66·92	249,390	253,670
June 1914.	130	913	1,460	388	....	4,807	2,891	3,500	4,200	257,900	39,500	62,000	25,500	67·97	284,600	286,900
Sept. 1914.	110	759	802	426	....	4,807	2,097	2,530	3,050	241,600	16,000	18,000	3,600	66·58	246,660	245,730
Oct. 1914.	90	591	592	355	....	4,807	1,628	1,960	2,360	229,900	14,800	16,000	2,800	66·17	233,460	234,660
June 1915.	169	512	854	501	....	4,807	2,036	2,460	2,960	221,900	60,000	102,000	49,000	67·69	266,860	273,360
Oct. 1915.	144	954	1,170	472	....	4,807	2,740	3,300	3,980	225,100	28,400	43,500	14,000	66·34	244,180	242,400
Nov. 1915.	119	819	1,150	549	....	4,807	2,637	3,200	3,830	219,800	25,400	38,200	11,300	66·06	236,430	234,300
May 1916.	3,360	5,530	5,210	2,010	....	4,807	16,110	19,400	23,400	264,200	119,500	225,000	119,500	71·49	393,100	403,100
22 May 1916.	16,980	1,300	5,970	6,650	....	4,807	39,900	48,100	57,900	267,000	132,000	262,000	134,000	72·47	454,900	449,100
13–22 June 1916.	1,600	3,000	2,600	1,100	....	4,807	8,300	10,000	12,000	279,800	84,000	140,000	78,000	70·57	351,800	367,800

NOTE.—Cols. (16) and (17) give discharge by alternative methods of calculation. The results are in fair agreement, but as those in Col. (17) appear more consistent, they have been selected to establish the curve.

TABLE NO. 1.—SHOWING DERIVATION OF DISCHARGE STAGE RELATION FOR LOCK 5, LACHINE GAUGE. PERIOD 1904 TO DATE—*Continued*

Date	S. Nation R. Disch. (Drainage A,=1,436 S.M.)	Oswegatchie R. Disch. (Drainage A.=961 S.M.)	Paquette R. Disch. (Drainage A.=723 S.M.)	St. Regis R. Disch. (Drainage A.=621 S.M.)	North R. Disch. (Drainage A=700 S.M.)	Total Drainage Area	Total Discharge	Disch. of Drainage A.L. 25–L.5= 5,800 S.M.Q.=5,800 x Col. (8) / Col. (7)	Disch. of Drainage A, Grenville to St. Annes=1,186 S.M. + That shown in Col. (9) Q=6,986 x Col. 8 / Col. 7	Lock 25 Disch.	Des Prairies R. Disch.	Grenville Disch.	Upper St. Annes (Vaudreuil) Disch.	Lock 5, Lachine W.Elev.	Total Disch. Cols. (10) + (11) + (13) − (12)	Total Disch. Cols. (9) + (11) +14)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
May 1917.	681	1,760	3,110	1,380	....	3,741	6,931	10,800	12,900	245,500	87,000	154,000	81,000	69·66	325,400	337,300
June 1917.	391	2,090	3,020	1,340	1,700	4,441	8,541	11,150	13,400	259,000	82,000	144,000	75,000	69·82	334,400	345,150
July 1917.	317	736	1,180	467	1,030	4,441	3,730	4,870	5,860	269,100	62,000	104,500	51,400	69·19	317,600	325,370
Sept. 1917.	159	623	409	376	400	4,441	1,967	2,560	3,090	257,900	30,500	44,500	16,000	67·70	274,990	276,460
May 1918.	459	2,630	3,340	....	1,590	3,820	8,019	12,180	14,650	261,600	72,000	124,000	64,000	69·62	328,250	337,780
June 1918.	391	1,630	1,780	....	860	3,820	4,661	7,070	8,510	261,100	55,500	86,000	43,500	68,181	300,110	311,670
Aug. 1918.	135	502	632	....	590	3,820	1,859	2,820	3,400	248,600	30,000	42,800	16,000	67·33	264,800	267,420

NOTE.—Cols. (16) and (17) give discharge by alternative methods of calculations. The results are in fair agreement, but as those in Col. (17) appear more consistent, they have been selected to establish the curve.

TABLE NO. 1.—SHOWING DERIVATION OF DISCHARGE STAGE RELATION FOR LOCK 5, LACHINE GAUGE. PERIOD 1904 TO DATE—*Concluded*

Date	S. Nation R. Disch. (Drainage A,=1,436 S.M.)	Rouge R. Disch. (Drainage A.=1,780 S.M.)	Rideau R. Disch. (Drainage A.=1,516 S.M.)	Mississippi R. Disch. (Drainage A.=1,400 S.M.)	Madawaska R. Disch. (Drainage A=3,210 S.M.)	Total Drainage Area	Total Discharge	Disch. of Drainage A.L. 25-L.5= 5,800 S.M.Q.=5,800 x Col. (8) / Col. (7)	Disch. of Drainage A, Grenville to St. Annes=1,186 S.M. + That shown in Col. (9) Q=6,986 x Col. 8 / Col. 7	Lock 25 Disch.	Des Prairies R. Disch.	Grenville Disch.	Upper St. Annes (Vaudreuil) Disch.	Lock 5, Lachine W.Elev.	Total Disch. Cols. (10) + (11) + (13) − (12)	Total Disch. Cols. (9) + (11) + (14)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
May 1919	2,110	12,230	4,490	4,290	10,600	9,342	33,720	20,850	25,240	268,900	121,000	225,000	121,000	71·45	398,140	410,750
1 June 1919	1,180	8,370	4,910	6,010	13,720	9,342	34,190	21,200	25,600	278,300	132,000	271,000	135,500	71·99	442,900	433,000
Oct. 1923	....	....	....	....	....	....	....	3,100	....	208,500	24,000	31,500	10,400	65·69	....	222,000
Sept. 1923	....	....	....	....	....	....	....	4,100	....	215,300	33,500	41,000	19,000	66·21	....	238,400
Nov 1923	....	....	....	....	....	....	....	3,400	....	202,100	25,500	34,000	12,000	65·73	....	217,500

NOTE.—Cols. (16) and (17) give discharge by alternative methods of calculations. The results are in fair agreement, but as those in Col. (17) appear more consistant, they have been selected to establish the curve.

TABLE NO. 2.—SHOWING DERIVATION OF DISCHARGE STAGE RELATION FOR LOCK 5, LACHINE GAUGE. PERIOD 1860–1877

Date	Discharge at Ste. Annes and Vaudreuil into Lake St. Louis	Discharge Coteau Landing	Discharge Richelieu River	Allowance for Drainage Area between Coteau Landing and Lock 5. 1,300 x —— Col 8,200 (4)	Total Discharge at Lock 5, Lachine Cols. (2) +(3)+(5)	Water Surface Elevation at Lock 5, Lachine
1	2	3	4	5	6	7
Sept. 6, 1872	10,000	239,700	19,500	3,300	253,000	65·90
June 1, 1873	151,700	292,000	26,000	4,400	448,100	71·67
Sept. 12, 1873	10,000	270,400	11,200	1,900	282,300	67·27
Oct. 31, 1873	37,000	267,000	14,200	2,500	306,500	67·49
June 1, 1874	121,000	298,000	27,100	4,800	423,800	71·07
May 17, 1876	212,700	323,000	37,600	6,300	542,000	73·74
May 26, 1877	42,000	270,300	13,200	2,300	314,600	68·72
Oct. 26, 1877	10,200	233,300	4,100	800	244,300	66·15

TABLE NO. 3.—SHOWING DERIVATION OF DISCHARGE—STAGE RELATION FOR LOCK NO. 1. LACHINE

W.L. at Upper St. Annes between 69·6 and 70·0

Date	Pt. Claire Gauge	Pt. Claire Discharge	Lock 1 Gauge
1	2	3	4
Oct. 21–22, 1923	66·73	217,900	18·01
Sept. 13–15, 1922	67·93	252,000	19·68
Sept. 29–30, 1922	67·72	245,800	19·31
Oct. 1– 4, 1922	67·65	243,400	19·16
Oct. 13–16, 1922	67·61	242,500	19·10
Oct. 30–31, 1922	67·30	233,500	18·73
Aug. 11–13, 1921	67·99	253,400	19·75
Aug. 27–30, 1921	67·71	245,500	19·09
Sept. 20–26, 1920	67·56	241,000	18·94
Oct. 8–10, 1920	67·56	241,000	19·13
W.L. at Upper St. Annes between 70·0 and 70·4			
Sept. 8–10, 1924	67·83	249,000	19·59
Oct. 7– 9, 1923	66·94	223,500	18·34
Oct. 18–19, 1923	66·75	218,200	18·28
Oct. 21–22, 1923	66·73	217,800	18·01
Aug. 15–16, 1922	68·45	267,500	20·27
Aug. 18–20, 1922	68·33	264,000	20·19
Aug. 30–31, 1922	68·05	255,800	19·96
Sept. 3– 5, 1922	68·08	256,800	19·79
Sept. 13–14, 1922	67·94	252,200	19·69
Sept. 16–19, 1922	67·88	250,200	19·60
Sept. 28–29, 1922	67·70	245,000	19·42
Oct. 17–18, 1922	67·62	243,000	19·14
Oct. 29, 1922	67·22	231,200	18·74
Nov. 1– 3, 1922	67·25	232,000	18·76
July 16–18, 1921	68·26	261,900	19·96
July 27–28, 1921	68·25	267,500	19·91
July 30–31, 1921	68·23	260,800	19·81
Aug. 1– 2, 1921	68·16	258,900	19·87
Oct. 24–25, 1921	67·57	241,300	19·56
Nov. 14, 1921	67·10	228,000	18·63
Aug. 23–24, 1920	67·79	247,600	19·42
Aug. 26, 1920	67·66	244,000	19·29
Sept. 5– 9, 1920	67·70	245,000	19·35
Sept. 20, 1920	67·70	245,000	19·24
Oct. 5– 6, 1920	67·82	248,800	19·91
Nov. 4, 1920	67·78	247,600	19·39

TABLE NO. 3.—SHOWING DERIVATION OF DISCHARGE—*Continued*

W.L. at Upper St. Annes between 70·4 and 70·8

Date	Pt. Claire Gauge	Pt. Claire Discharge	Lock Gauge
1	2	3	4
Aug. 23–25, 1924	68·03	255,000	19·95
Aug. 16–28, 1924	68·11	257,100	19·99
Sept. 12, 1924	67·81	248,300	20·18
Aug. 5– 8, 1923	67·68	244,600	19·30
Aug. 9–11, 1923	67·57	241,300	19·11
Aug. 23–24, 1923	67·57	241,300	19·25
Sept. 3, 1923	67·46	238,000	19·15
Sept. 8– 9, 1923	67·36	235,200	18·91
Oct. 4, 1923	67·09	227,500	18·72
Nov. 1– 4, 1923	66·90	222,200	18·48
Nov. 5– 7, 1923	66·89	222,000	18·54
Nov. 16, 1923	66·72	217,500	18·39
Aug. 4– 5, 1922	68·56	271,000	20·66
June 28–29, 1921	68·54	270,400	20·46
July 1– 4, 1921	68·41	266,300	20·24
July 13–15, 1921	68·34	264,200	20·20
Oct. 26–29, 1921	67·31	234,000	19·20
Aug. 22–23, 1920	67·79	247,700	19·46
Aug. 27–28, 1920	67·67	244,100	19·25
Nov. 6– 7, 1920	67·73	246,200	19·49

W.L. at Upper St. Annes Between 70·8 and 71·2

Aug. 7–10, 1924	68·22	260,300	20·42
Aug. 11–13, 1924	68·32	263,500	20·47
Sept. 22–24, 1924	67·92	251,400	19·93
Setp. 27, 1924	67·61	242,200	19·55
July 24–26, 1923	67·93	252,000	19·85
Sept. 17–19, 1923	67·40	236,300	19·24
Sept 23, 1923	67·16	229,300	18·98
July 17–19, 1922	68·98	284,000	20·98
July 20–21, 1922	68·98	284,000	21·03
July 31–Aug. 2, 1922	68·65	273,900	20·86
June 17–19, 1921	68·77	277,500	21·02
July 5– 7, 1920	68·16	258,300	20·29
Aug. 6– 9, 1920	68·02	254,400	19·84
Aug. 10–12, 1920	68·03	255,000	19·85

W.L. at Upper St. Annes between 71·2 and 71·6

July 24–30, 1924	68·54	270,200	20·83
Oct. 9–11, 1924	68·22	260,200	21·00
July 20–23, 1923	68·12	257,500	20·05
July 1– 7, 1922	69·50	300,900	22·39
July 22–23, 1922	68·93	282,500	21·06
June 14–17, 1921	68·93	282,500	21·25
June 24–26, 1920	68·22	260,200	20·32
June 29–30, 1920	68·17	259,000	20·10
July 2– 3, 1920	68·05	257,800	20·12
July 23–29, 1920	68·29	262,800	20·41
July 20–25, 1919	69·47	300,000	21·64
Oct. 7– 8, 1919	68·85	280,000	21·12
July 30–31, 1918	69·05	286,800	21·49
Aug. 1– 5, 1918	68·75	276,800	20·97
Sept. 30–Oct. 3, 1918	68·64	273,500	20·99
Aug. 27–31, 1917	69·28	293,600	21·60
Sept. 9–11, 1917	68·90	281,800	20·97
Nov. 5– 8, 1917	69·09	287,400	21·82

TABLE No. 3.—SHOWING DERIVATION OF DISCHARGE—*Concluded*

W.L. AT UPPER ST. ANNES BETWEEN 71·6 AND 72·0

Date	Pt. Claire Gauge	Pt. Claire Discharge	Lock 1 Guage
1	2	3	4
July 9, 1924	68·70	275,400	21·09
July 12–15, 1924	68·61	272,600	20·73
Oct. 5, 1924	68·76	277,000	22·16
Oct. 7–10, 1924	68·40	266,000	21·35
July 10–12, 1923	68·40	266,000	20·49
June 20, 1922	69·42	298,200	22·64
July 1, 1922	69·55	302,600	22·72
June 13, 1921	69·07	287,000	21·34
June 15, 1920	68·42	266,800	20·72
July 9–12, 1919	69·80	311,000	22·06
Oct. 16–18, 1919	68·86	280,200	21·28
Oct. 19–22, 1919	68·73	276,200	20·94
Nov. 16–17, 1919	68·94	283,000	21·35
July 30–31, 1918	69·05	286,700	21·50
Oct. 12–15, 1918	69·00	285,000	21·66
Oct. 16–18, 1918	68·72	276,000	21·28
Aug. 16, 1917	69·52	301,900	22·10
Aug. 25–28, 1917	69·32	295,000	21·69
July 21–22, 1916	69·69	307,000	22·32
June 9–11, 1915	68·06	256,100	20·11
June 19–22, 1915	68·04	255,800	20·31
June 23–25, 1915	67·98	253,100	20·41
July 5– 8, 1915	67·94	252,400	19·93

W.L. AT UPPER ST. ANNES BETWEEN 72·4 AND 72·8

Date	Pt. Claire Gauge	Pt. Claire Discharge	Lock 1 Guage
June 21–22, 1923	68·96	283,200	21·73
June 5– 3, 1922	69·44	298,700	22·05
May 30–31, 1921	69·53	301,900	22·03
June 1– 3, 1921	69·42	298,300	21·88
July 6, 1919	70·05	320,000	22·80
June 17–23, 1918	69·65	305,800	22·44
Aug. 2, 1917	70·08	320,700	23·00
July 7–10, 1916	70·17	363,600	23·20
June 5, 1915	68·21	260,100	20·59
June 13–15, 1924	69·77	310,000	23·06
May 18–20, 1921	70·17	324,000	23·30
May 14–17, 1920	69·49	300,200	22·95
June 24–26, 1919	70·80	346,000	23·86
June 1– 3, 1918	70·46	334,000	23·29
June 28–29, 1916	70·89	349,000	24·45

W.L. AT UPPER ST. ANNES BETWEEN 74·8 AND 75·2

Date	Pt. Claire Gauge	Pt. Claire Discharge	Lock 1 Guage
May 2, 1924	70·34	330,000	24·67
May 23–25, 1922	70·76	344,800	24·40
April 30–May 2, 1921	70·80	346,000	25·12
May 15–19, 1917	70·63	340,000	24·81
May 30–31, 1917	70·44	332,700	24·07
June 1– 4, 1917	70·64	340,800	24·04
June 12–13, 1916	71·40	368·000	25·58

TABLE No. 4.—SHOWING DERIVATION OF DISCHARGE STAGE RELATIONS AT VARENNES AND SOREL

Date	Discharge Pt. Claire and Des Prairies River	Discharge Richelieu	Discharge St. Francis	Discharge St. Maurice	$\frac{1,850}{16,200}$ of St. Maurice discharge	One-half Richelieu discharge	One-third St. Maurice discharge	Total flow at Varennes 2+6+7+8	Gauge at Varennes	Total flow at Sorel 2+3+4+5	Gauge at Sorel
1924											
26th April to 2nd May	398,000	29,500	19,500	56,800	6,500	14,800	18,900	438,200	22·06	503,800	18·94
11th May to 17th May	455,300	34,600	9,200	136,100	15,500	17,300	45,400	533,500	24·06	635,200	21·02
26th May to 1st June	465,600	24,500	4,300	18,300	9,300	12,300	27,100	514,300	23·49	575,700	19·75
9th June to 15th June	386,900	17,800	2,900	35,400	4,000	8,900	11,800	411,600	20·59	443,000	16·95
9th July to 15th July	312,700	8,300	1,800	18,800	2,200	4,200	6,300	325,400	17·75	341,600	14·30
24th July to 30th July	336,900	6,000	4,700	24,200	2,800	3,000	8,100	350,800	17·80	371,800	14·37
7th August to 13th August	293,500	4,700	8,000	24,700	2,800	2,400	8,200	306,900	17·45	330,900	14·27
23rd August to 29th August	284,400	4,000	2,600	14,500	1,700	2,000	4,800	292,900	16·87	305,500	13·59
6th September to 12th September	272,100	4,000	22,300	30,000	3,400	2,000	10,000	287,500	16·69	328,400	13·93
21st September to 27th September	280,000	4,300	4,300	26,000	3,000	2,200	8,700	293,900	16·90	314,600	13·63
1923											
23rd April to 29th April	457,100	30,300	25,100	34,300	....	15,200	....	....	....	546,800	19·38
8th May to 14th May	465,100	38,200	11,300	102,200	11,700	14,100	34,100	525,000	23·80	606,900	20·42
23rd May to 29th May	463,100	24,600	6,800	65,300	7,500	12,300	21,800	504,700	23·46	559,800	19·81
7th June to 13th June	403,400	19,600	8,900	19,700	2,300	9,800	6,600	422,100	20·82	451,600	17·10
21st June to 27th June	326,800	14,600	3,500	15,100	1,700	7,300	5,000	340,800	18·45	360,000	15·10
6th July to 12th July	311,600	9,400	4,400	13,900	1,600	4,700	4,600	322,500	17·77	339,300	14·24
20th July to 26th July	289,600	6,100	2,100	12,900	1,500	3,100	4,300	298,500	17·06	310,700	13·81
5th August to 11th August	270,500	4,300	1,900	13,900	1,600	2,200	4,600	278,900	16·26	290,600	12·98
19th August to 25th August	267,800	3,600	2,300	15,800	1,800	1,800	5,300	276,700	16·27	288,700	13·16
3rd September to 9th September	263,900	2,600	1,600	18,100	2,100	1,300	6,000	273,300	16·18	286,200	12·98
17th September to 23rd September	265,400	1,600	2,300	16,700	1,900	800	5,600	273,700	16·33	286,000	13·09
3rd October to 9th October	250,200	1,800	2,300	13,600	1,600	900	4,500	257,200	15·56	267,900	12·41
17th October to 23rd October	240,600	1,300	2,000	14,100	1,600	700	4,700	247,600	15·36	258,000	12·23
1st November to 7th November	248,300	3,000	3,100	19,000	2,200	1,500	6,300	258,300	15·68	273,400	12·68
16th November to 22nd November	243,600	3,600	2,500	15,600	....	1,800	....	....	....	265,300	12·33
1922											
4th May to 10th May	468,000	31,600	7,500	56,200	6,400	15,800	18,700	508,900	23·47	563,300	19·73
19th May to 25th May	430,300	23,400	3,200	37,600	4,300	11,700	12,500	458,800	21·76	494,500	17·91
2nd June to 8th June	356,800	17,400	3,800	24,100	2,800	8,700	8,000	376,300	19·40	402,100	15·92
17th June to 23rd June	342,000	20,300	19,900	23,300	2,700	10,200	7,800	362,700	20·07	405,500	17·45
1st July to 7th July	367,800	21,100	13,600	24,300	2,800	10,600	8,100	389,300	19·47	425,800	16·20
17th July to 23rd July	317,200	14,900	2,700	20,500	2,300	7,500	6,800	333,800	17·81	355,300	14·53
31st July to 6th August	301,100	10,500	2,500	20,600	2,400	5,300	6,900	315,700	17·60	334,700	14·48
15th August to 21st August	289,300	8,300	3,500	16,200	....	4,200	5,400	....	....	317,300	13·81

30th August to 5th September	279,900	5,900	2,700	17,700	2,000	3,000	5,900	290,800	16·80	306,200	13·64
13th September to 19th September	273,600	4,800	2,300	30,300	3,500	2,400	10,100	289,600	16·58	311,000	13·43
28th September to 4th October	265,100	3,600	1,900	18,000	2,100	1,800	6,000	276,000	16·19	288,600	13·00
13th October to 19th October	263,400	3,600	2,700	28,200	3,200	1,800	9,400	277,800	16·00	297,900	12·83
28th October to 3rd November	254,700	1,700	3,200	19,400	2,200	900	6,500	264,300	15·73	279,000	12·59
1921											
30th April to 6th May	434,000	20,700	5,300	113,600	13,000	10,400	37,900	495,300	22·76	573,600	19·33
14th May to 20th May	401,200	15,100	2,600	33,600	3,800	7,600	11,200	423,800	20·87	452,500	17·14
30th May to 5th June	347,200	11,300	2,300	21,400	2,400	5,700	7,100	362,400	18·89	382,200	15·17
13th June to 19th June	317,000	7,100	2,300	25,200	2,900	3,600	8,400	331,900	18·25	351,600	14·81
28th June to 4th July	295,300	5,200	1,700	17,600	2,000	2,600	5,900	305,800	17·35	319,800	14·03
12th July to 18th July	288,100	4,600	1,800	19,600	2,200	2,300	6,500	299,100	17·13	314,100	13·73
27th July to 2nd August	284,000	3,800	1,700	18,900	2,200	1,900	6,300	294,400	16·81	308,400	13·41
11th August to 17th August	273,300	2,500	2,100	15,000	1,700	1,300	5,000	281,300	16·52	292,900	15·19
25th August to 31st August	265,300	2,100	1,900	12,300	1,400	1,100	4,100	272,900	16·21	281,600	12·92
27th September to 3rd October	247,600	1,400	1,800	22,600	4,600	700	7,500	258,400	15·56	273,400	12·63
9th October to 15th October	251,400	200	3,700	32,700	3,700	100	10,900	266,100	15·94	288,000	12·96
23rd October to 29th October	262,100	900	3,200	45,300	3,200	500	15,100	282,900	16·67	311,500	13·59
8th November to 14th November	253,000	900	2,400	19,900	2,300	500	6,600	262,400	15·81	276,200	12·63
22nd November to 28th November	269,300	4,600	6,700	22,500	....	....	....	....	....	305,100	13·98
1920											
25th April to 1st May	389,800	38,900	26,200	66,800	7,600	19,500	22,300	439,200	22·11	521,700	19·00
11th May to 17th May	371,900	30,300	6,100	60,300	6,900	15,200	20,100	414,100	20·66	469,600	17·26
25th May to 31st May	344,000	23,000	2,200	57,300	6,800	11,500	19,800	382,100	19·72	428,500	16·38
9th June to 15th June	313,800	15,600	2,200	34,700	4,000	7,800	11,600	337,200	18·24	366,300	14·77
24th June to 30th June	295,900	10,800	1,200	20,800	2,400	5,400	6,900	310,600	17·28	328,700	13·84
2nd July to 8th July	292,400	9,800	2,300	30,000	3,400	4,900	10,000	310,700	17·41	334,300	14·21
23rd July to 29th July	299,500	8,100	1,900	24,400	2,800	4,100	6,100	314,500	17·61	333,900	14·06
6th August to 12th August	285,700	5,900	1,300	15,400	1,800	3,000	5,100	295,800	17·00	308,500	13·65
22nd August to 28th August	269,000	4,900	1,000	21,400	2,400	2,500	7,100	281,000	16·44	296,300	13·11
5th September to 11th September	269,200	3,700	1,900	14,900	1,700	1,900	5,000	277,800	16·56	289,700	13·42
20th September to 26th September	261,900	4,200	3,400	13,800	1,800	2,100	5,300	271,100	16·00	285,300	12·62
4th October to 10th October	267,100	7,300	4,300	16,700	1,900	3,700	5,600	278,300	16·74	295,400	13·55
20th October to 26th October	251,300	6,300	2,700	15,400	1,800	3,200	5,100	261,400	15·56	275,700	12·73
3rd November to 9th November	271,000	6,600	6,900	21,900	2,300	3,300	7,300	284,100	16·56	306,400	13·42

APPENDIX E

ICE FORMATION ON THE ST. LAWRENCE AND OTHER RIVERS

1. When the problem of preparing plans for the improvement of the St. Lawrence river was first undertaken, particularly by the Canadian Government, about ten years ago, there was a great deficiency of basic data on which to predicate designs. Since that time systematic surveys have been made of ice covers, packs and gorges, as they occur, and as a result of these, much exact knowledge is now available. This data is presented in summary in this appendix.

2. Ice Pressure. In northern latitudes a solid covering of ice forms on quiet river and lake surfaces in winter. This melts away with the advent of warm weather. The thickness of ice cover varies with the coldness of the climate. A thickness of about 2.5 feet is found in latitude 45 and 5.5 feet in latitude 57 in the eastern half of North America. Sheet ice as formed on lakes and rivers is made up of great numbers of crystals standing with axes vertical and closely packed side by side. As the air with which ice is in contact changes in temperature from day to day, the temperature of ice on rivers and lakes changes also. In cases where the ice surface is free from snow, the amplitude of this change at mid depth is about one-half that of the air so long as the temperature of the air is below freezing. If an ice sheet is covered with snow this change in amplitude is less than one-half that of the air.

3. As ice heats and cools it expands and contracts. Daily expansion and contraction of ice sheets is noticeable on lakes and rivers in northern regions. In some cases cracks have been observed to open or close as much as ten feet in a period of several days and these usually occur in the same places year after year.

4. The coefficient of free unrestrained expansion of ice is given by many authorities as about .00004 per degree Fahrenheit change in ice temperature per unit of length. On this basis a sheet of ice one mile long, with a temperature change of 5 degrees, would expand or contract to the extent of one foot. Actually, movements of two feet per mile have been observed at free ends of ice sheets on large lakes and rivers during extreme changes of weather. On small lakes and rivers, the movement of the ice is believed to be restrained by the shores at least to a sufficient extent to prevent it being much noticed.

5. There are records of failure of some light dams and structures which were due to ice action but the fact that dams of dimensions not sufficient to resist theoretical ice action are in place, proves that the full crushing strength of ice is not applied to them.

6. In order to set up a more definite value for probable ice pressure on dams, a series of tests were carried out by Professor Ernest Brown of McGill University and the engineering staff of the Department of Railways and Canals in the winter of 1925-26. These show that sheets of ice flow or slowly change their shape as soon as subjected to pressures in excess of about 100 pounds per square inch. A special report giving details of tests made in this connection is given in appendix "F".

7. In view of the foregoing, the Board has reached the conclusion that ice pressure will not exceed 22,000 pounds per linear foot on the upstream side of dams under weather conditions to be expected in the St. Lawrence region.

8. Ice Formation in Rapid Water. As is well known, the precipitous rapids of northern rivers remain open in winter and solid smooth ice covers form on the gently flowing sections; thus, open and closed conditions alternate with one another. The laws or conditions governing the location of the boundaries between an open and closed surface are not well known. Observations of the behaviour of rapids and open stretches of river show that they are subjected to much cooling in winter, but they do not freeze over because the ice crystals formed in preserving the heat equilibrium, attach themselves to the bottom or are carried off by the turbulent water before they have time to connect to one another or bridge the stream. As the water with its burden of ice moves downstream it ultimately reaches a river or lake expansion where its velocity and turbulence moderate and where the ice and slush move quietly on its surface. Under these conditions ice bridges form across the river or lake and then the pack, as it is called, advances upstream until it reaches a point where the velocity becomes so great that ice is carried under the surface of the pack and is deposited there in the form of a "hanging dam". These hanging dams continue to increase in length as long as the temperature of the air is below about 20 degrees Fahrenheit, or while snow is falling and as long as large open surfaces remain in the river above. As soon, however, as the temperature of the air rises above 20 degrees Fahrenheit or the area of the water surface exposed above reduces in size, the length and steepness of the water slope through these dams becomes less, and in the warm weather of approaching spring the jam melts away. The formation of an ice cover on a stream acts as a blanket and prevents the formation of frazil in the water beneath.

9. Sometimes ice gorges cause the inundation of large areas above them as in the vicinity of Montreal and sometimes they greatly reduce the flow of water as in the St. Clair river.

10. Effect on Power Improvement. In the improvement of northern rivers for power it is usually possible to establish water surface levels high enough to secure low velocities and eliminate or reduce to small proportions all water surface areas remaining open in winter. This opportunity is generally available because most rivers have deep wide valleys with small winter flows compared with those of summer.

11. Much difficulty is found in reducing open water areas on the St. Lawrence river to small proportions. The river carries a large winter flow which must be maintained, the river valley is relatively narrow and the water level at the head of the rapids sections cannot be raised on account of property values involved in flooding.

12. As a consequence of this situation a number of investigations were made to determine the facts with regard to the following matters:—

(*a*) Conditions under which smooth ice covers, ice packed covers, and hanging dams may be expected to form.

(*b*) The amount of ice formed by a given open water exposure in a given locality.

(*c*) The loss in head due to ice covers and packs of various kinds, or the effect of such packs on the flow of water under them.

13. Factors Affecting Ice Covers. Whether an ice cover forms or does not form across a river depends upon the temperature of the air, the temperature of the water, the velocity of the wind, and the velocity and turbulence of the water.

14. Actual observations at a number of points on the St. Lawrence show little variation in what takes place at a given point from year to year. For

instance, an ice cover always forms on lake St. Louis at a point where the average velocity is about one foot per second and gradually makes downstream to a point where the average velocity is close to two feet per second. An ice cover forms at the lower end of lake St. Peter at a point where the average velocity is from 1.0 to 1.25 feet per second. At the foot of Vercheres Island where the average velocity of the water is about 1.4 feet per second, ice covers do not form until the ice pack reaches this point from below. At other points on the river, such as the sections at Croil island, Cat island and at Drummond island, ice covers do form at from 1.30 to 1.40 feet per second, under extremely cold weather conditions. After an ice cover has started in quiet water near shore it will extend into swifter water. The actual surface velocities along the edge of an ice sheet have been observed to be as high as 2.5 feet per second.

15. The term "average velocity" as herein used is the velocity determined by dividing the river discharge by the area of the cross section at the water level. The term "surface velocity", where used, is the observed velocity determined by surface floats. The surface velocity at a section may be as much as 50 per cent in excess of the average velocity.

16. It is not probable that an ice cover would always form on a section of the St. Lawrence early in winter unless provision is made for reduction of the average velocity in the section to about 1.25 feet per second.

17. After ice covers are formed and attain some thickness it is found that average velocities can be increased up to 2.5 feet per second without danger of breaking up the ice sheet. This is current practice in the operation of power canals in the St. Lawrence district.

18. Near the immediate outlet of large lake expansions and in some rivers in Ontario large openings or air holes are sometimes found where the velocity is below one foot per second. This phenomenon is apparently caused by heat accumulated remaining in the water underneath the ice. Not many cases of this are found in the St. Lawrence where the velocity is so low, but the phenomenon is noticeable at the outlet of Rice lake on the River Trent and in other places.

19. In stretches of river where average velocities exceed 1.40 feet per second, ice covers will not form from shore to shore but after a bridge is formed below, ice and slush will pack upstream against an average velocity up to 2.25 feet per second without the floating slush or crystals being carried underneath the advancing ice bridge. This fact permits channels of reasonable size to be used for power works in northern latitudes, and is of economic importance in reducing the cost of improving rivers to obtain the power available in them.

20. The formation of the ice pack which forms each winter at the foot of lake St. Peter and gradually builds up to Montreal has been watched for many years, because it furnishes information of special value in connection with ice packs. Gauges were established in this stretch of river twelve years ago and water level records are available which show the change in slope which occurs in this reach as the ice pack advances from day to day.

21. From the above records and direct observations, the conditions under which the ice pack failed to advance have been clearly defined. If slush or frazil is carried underneath an ice bridge and is deposited in the form of a hanging dam its presence is reflected in steep slopes which continue throughout the winter. If the ice bridge advances without slush or frazil being carried underneath the cover, the section will not show any slush in place and surface slopes in succeeding winters will be moderate and uniform.

22. The observed data are shown on table No. 1. This table shows that frazil is likely to be carried under the ice cover and deposited if the average

velocity exceeds 2.25 feet per second, but is not ordinarily carried under unless the velocity exceeds that figure. The section chosen at Lanoraie is one in which the conditions are as adverse as can be expected anywhere.

23. On account of the need for reliable information on this matter an effort has been made to obtain corroborative data in other parts of the river. This search has only been partly successful as no other section is available which is naturally suited to furnishing such information. In the International Section of the St. Lawrence river and on the Niagara river, records show ice packs advancing upstream under velocities which may vary from 2.4 to 3.2 feet per second depending upon the temperature of the air and the amount of frazil and slush ice carried in the water (table 2). These velocities may also depend to some extent on the crookedness of the river as records in general show higher velocities at the head of advancing packs in the International Section than in the St. Lawrence below Montreal. Records also show the average velocity of the water at the point where deposits of frazil and slush cease at the lower ends of hanging dams to be about 2 feet per second. It is probable that some ice is generally carried under sections when the ice pack is advancing, but obviously the point where it would cease to be carried under is near at hand else the pack would not advance. Again, the fact that water does not carry ice under a cover at a velocity less than 2 feet per second suggests that velocities of less than 2.25 feet per second would not cause it to submerge. Records of receding ice jam is during the breakup period (table 3) indicate that the average velocity of the water at the head of the jam in these cases varies from 2.2 to 2.5 feet per second.

24. The deduction made from this information is that an average velocity of less than 2.25 feet per second must be provided to ensure an unobstructed section, especially in mild weather immediately following cold periods.

25. Limiting Velocities for Advance of Ice Packs. In the improvement of the St. Lawrence it is important to define conditions under which a stretch of river will remain open and free from ice covers of all kinds. River channels were cross-sectioned in winter and re-cross-sectioned in summer; flows were metered in winter and in summer, and every effort was made to ascertain the truth in each case which appeared to furnish typical information. A variation is found in the velocity and temperature required to produce a bridge in different sections of the river. This is shown by table 2.

26. An examination of data accumulated shows that with velocities between 2.7 and 3.3 feet per second ice covers, if formed, will go and come with changes of weather but, with velocities in excess of about 3.3 feet per second, surfaces will generally remain open under all winter conditions on the St. Lawrence.

27. Rates of Ice Production. In addition to determining the water velocity conditions under which ice covers and packs of various kinds are formed, the volume of ice in the form of frazil made by a given exposure to cold is important because it is not always possible to arrange for the whole of a river to be ice covered. Two methods for determining this volume are available.

28. The actual contents of hanging dams in lake St. Louis, lake St. Francis, and above Croil island have been measured by cross-sections under the ice at these points. The measurements made when related to the water surface exposed show the production of from 8 to 15 cubic feet of ice per square foot of exposure. These variations depend upon the place of measurement and the coldness of the winter in the year in question.

29. Another method of arriving at the volume of ice formed is by the establishment of the rate at which a water surface loses heat previous to its being cooled down to the freezing point in the fall of each year and the application of the rate found to later exposures. The temperature of both air and water was recorded at Kingston, Brockville, Drummond Island, Dickinson's Landing, Cornwall, Hamilton island and Coteau, for periods of about two months previous to the actual formation of ice in the years 1924 and 1925.

30. By relating heat losses to differences in temperature found between air and water, the rate of transfer of heat between surfaces was established with a fair degree of accuracy. An examination of the statement attached (table 10) shows that this rate may be taken at about 95 British Thermal Units transferred per day per square foot per degree difference in temperature between air and water, and is independent of the character of the river sections in question. That is, the surface of rapids, the surface of lakes and the surface of smooth sections of river all give about the same cooling coefficient or rate of heat transfer.

31. As shown from an inspection of diagrams which have been prepared, the coefficient derived from these measurements is affected in some degree by snowfall, rainfall and wind. A correction for the effect of snowfall and rainfall has been made in the results given but the effect of wind cannot easily be taken into account. As its effect is small compared to the general difference in temperature between air and water it may be disregarded in the use of this data.

32. As one pound of ice is formed by water at 32° Fahr. giving up 144 British Thermal Units, the total amount of ice formed by a given length of the river in a given time can be approximately determined from temperature records. During the winter of 1924-25, for a period of 80 days the average temperature of the air in the vicinity of Montreal was 17·6° Fahr. below the freezing point, making an aggregate of 1,410 degree days. Taking the cooling coefficient of 95 British Thermal Units per degree day given in paragraph 30, it will be found that this exposure accounts for 16·3 cubic feet of ice per square foot of surface. Actually, 14·4 cubic feet of slush per square foot of surface exposed was found by measurement under the solid ice cover at the head of lake St. Louis at the end of that winter, as shown on table 4. Similarly, in the year 1923 the water surface area exposed in the vicinity of Ogdensburg was subjected to 1,246 degree days of freezing which should form theoretically 14·2 cubic feet per square foot of surface exposed. Cross-section measurements made at the head of lake St. Francis show a deposit of 13·0 cubic feet per square foot of surface exposed between lake St. Francis and Ogdensburg. Other measurements in other years indicate similar relations, as shown on table 4.

33. An approximation of the volume of ice formed by a given exposure can also be made from the rate at which ice packs make upstream from Lanoraie to Longue Pointe below Montreal in zero weather. If cold weather comes on gradually in winter lake St. Peter freezes over a few days before lake St. Louis or lake St. Francis and the area of water at the freezing point can be approximated from temperature measurements at a number of points in this section of the river.

34. In the year 1925-26 specially good means were provided for estimating the area forming ice because lake St. Francis in that year froze three days before lake St. Louis, and lake St. Louis was open while the pack advanced from Lanoraie to Longue Pointe. In that year the temperature of the water coming down the river reached the freezing point at Cedars about the time the ice pack reached Sorel coming up, but a high west wind kept lake St. Louis open while the pack advanced up stream to Vicker's dry-dock, just below Montreal. The

actual travel of the pack upstream during the two days with 27 degrees of freezing was fifteen miles. With ice taken as fifteen inches thick 25,500,000 cubic yards would be formed or accumulated in one day in this section of the river. This gives about the same volume as is derived by the use of 95 as the cooling coefficient and 77 square miles as the area of surface exposed at that time.

35. An inspection of tables No. 5 and 6 indicates that the degree days of freezing to which water surfaces are exposed in the vicinity of Kingston, after they reach a freezing temperature, is only about 80 per cent, and at Ogdensburg 90 per cent of that to which similar areas are exposed at Montreal. This difference is due to the moderating influence of lake Ontario on the temperatures of both air and water in the upper river as well as to differences in latitude.

36. The general seasonal variations in temperature of the air and water all along the St. Lawrence from lake Ontario to Montreal are shown in a number of diagrams which are attached to this Appendix (plates 1 and 2). These show the manner in which the great volume of water held in lake Ontario lengthens the season of open water to a decreasing extent all the way down the river from Kingston to Montreal. On account of the proximity of lake Ontario water, temperatures opposite Kingston at the beginning of winter are still 9 degrees above the freezing point when the inflow from the Ottawa river at the head of lake St. Louis reaches the freezing point. The temperature of the water at Kingston is generally about 6 degrees above the freezing point when the water at the foot of lake St. Peter, 65 miles below Montreal, reaches the freezing point. Usually ice begins to form opposite Kingston at the head of the St. Lawrence about sixteen days after the ice begins to form on lake St. Peter below Montreal and almost a month after ice begins to form on lake of Two Mountains at the outlet of the Ottawa river.

37. Early in the spring of the year, warmer water from the depths of lake Ontario makes itself felt and ice generally disappears in the stretch of river above Ogdensburg about two weeks before a through channel is available at the head of lake St. Louis and lake St. Peter. However, as soon as lake St. Louis and lake St. Peter are clear of ice the temperature of the water at these points rises rapidly and is soon found to be higher than that flowing out of lake Ontario. Throughout the early summer months the temperature of the water downstream from lake Ontario is tolerably uniform at all points.

38. As a consequence of the above conditions the winter or ice-covered period in the St. Lawrence at the head of the International section is about one month shorter than that of the river in the vicinity of Montreal.

39. In addition to considering the amount of frazil created by a given exposure, consideration should be given to the fact that water which flows for any great length of time underneath an ice cover, even in winter, accumulates a certain amount of heat from some source. Temperature measurements of the water at the foot of lake St. Francis and at the foot of Bergan lake show that the water flowing out of these ice-covered sections is about 0·03 of a degree warmer than freezing throughout the whole winter period from the time the ice is formed until soft slush makes its appearance on the surface of the ice in March. Measurements also show the temperature of the water under the ice is about 0·16 of a degree warmer than freezing opposite Clayton and 0·08 of a degree warmer than freezing at Prescott during the coldest part of the winter. This heat has an important bearing on the design of works, especially at Galop rapids. If the flow of the river in winter be taken at 200,000 cfs. and the average temperature of the weather as 20 degrees below freezing, it will require an exposure of 45,000,000 square feet to cool the water to the freezing point.

This means that three miles of open water may exist at this point and yet no frazil on the average accumulate, as cold weather is always succeeded by warmer spells and the average temperature for winter months seldom falls below +12° Fahrenheit.

40. Slopes through Ice Covered Sections. Gauge relations show that even the smoothest forms of ice covers impose resistance to the flow of water in the sections which they cover. This is easily seen by comparison of summer and winter slopes between Summerstown and Coteau, on lake St. Francis, Ottawa and Grenville, on the Ottawa river, Peterborough and Hastings, on the Trent, and the slopes in certain canals where the discharge is known.

41. The data gathered with regard to the resistance of this form of ice cover indicate that it is comparable to the resistance of concrete surfaces. In canals where a value of "M" in Bazin formula, of 4.0 satisfied summer conditions a value of 2.3 will satisfy winter conditions, the ice cover being taken as part of the wetted perimeter. A value of "M"=1.0 averaged with the value established for open water conditions will give its value close enough for practical purposes.

42. The resistance to flow caused by an ice cover formed by the accumulation of slush and frazil at the head of an advancing ice bridge is of great importance in the design of the St. Lawrence Project, and elaborate arrangements were made to establish values for this form of resistance.

43. Special gauges were established at Varennes, Repentigny and Lavaltrie on the St. Lawrence river below Montreal. These were read winter and summer for two years and slopes were related to discharges derived from gauges farther up river. Through this section of the river no deposits of frazil are found and average summer velocities vary from 2 to 2.6 feet per second while winter velocities vary from 1.3 to 1.6 feet per second, depending upon the state and discharge of the river. From these relations and actual cross-sections of the river made winter and summer, values of "M" in the Bazin formula were obtained. These are shown on table No. 7.

44. Gauge readings between Lanoraie and Sorel and discharge relations were also used to determine values for these years in which it was apparent no frazil or slush was carried into the section (table 8). The values obtained in this way check closely with those obtained in the section first described. In this reach velocities vary from 2 to 3.4 feet per second in summer, to 1.6 to 2 feet per second in winter.

45. The data above described indicate that winter slopes on the St. Lawrence river may safely be figured with a value of "M" in the Bazin formula taken as the average between that applicable to summer conditions and 5.5 for January and 4.5 for February and March. All the values of "M" derived from gauge readings show a gradual smoothing of the ice cover as the season advances from the time it is first formed until it begins to melt out in the month of March.

46. The foregoing results apply to ice covers when formed as a packed surface without hanging deposits. The slopes occurring when all kinds of ice are carried underneath the section and lodged in the form of hanging dams, jams or gorges require consideration.

47. A number of ice jams or gorges occur on the St. Lawrence each winter. One of these is at the head of lake St. Francis; one is at the head of lake St. Louis; and one is opposite the city of Montreal between the foot of Lachine rapids and Longue Pointe. In addition to these, occasional jams occur between Morrisburg and Croil island and in the Niagara river.

48. The gorge at the head of lake St. Francis has been watched with care for a number of years and slopes obtained in this section are interesting but, as the river is divided at this point by Cornwall island, deductions from records must be made with care.

49. The gorges which occurred in the river between Morrisburg and the foot of Croil island were especially instructive. Those which occurred at this point in 1887 and in 1905 also furnish information of value, though the records of these jams are not complete. When the jam of 1923 occurred the Department of Railways and Canals placed a large staff of men at recording the phenomena, and records of great value were obtained.

50. In 1925 an extensive gorge occurred in the lower Niagara river. This jam was especially instructive in view of the straight uniform character of the river. The water level at the head of this jam and the volume of the ice in the section were carefully determined by surveys carried out by the Department of Railways and Canals.

51. The surface slopes opposite Montreal have been recorded for a number of years. Many cross-sections of jams near Montreal were made by the Montreal Flood Commission in 1887. The gorge at the head of lake St. Louis was cross-sectioned by the staff of the Canadian section of this Board in 1925.

52. From the surface irregularity of ice jams it might appear that no prediction could be made as to the form which such jams take or as to the slope of the water surface flowing through them. Many cross-sections, however, disclose the fact that these hanging dams tend to assume a definite shape with ribbons of clear water of uniform sectional area flowing underneath the jam.

53. Just after an ice movement or a consolidation of a jam the underlying ribbon of water is often irregular but it soon changes to the typical and regular form. The average velocity of the water in the resultant section is generally about three feet per second but does reach four feet per second in some cases and also falls to two feet per second at the foot of gorges in mild weather.

Typical sections of jams are shown on plates 12 and 13.

54. Observations of gorges during formation show that frequently there is a series of pushes in the upper part of the gorge in which the cover at the head is telescoped and on-coming ice from the upper part plunges under the lower part in a continuous stream which sometimes keeps moving for a full day at a time. These partly compressed coverings of ice in pushing down the river bend around curves and change their shape with difficulty. Ice coverings appear to make upstream against higher velocities in crooked channels than they do in straight reaches.

55. The observed slopes of the St. Lawrence through ice jams are shown on table 9. These are plotted on plate No. 7. This plate shows that surface slope in feet per mile is always greater after heavy snowfalls than even during periods of intensely cold weather.

56. Records as plotted on plates 3 to 6 show that the advent of moderate weather succeeding cold periods or periods of snowfall always produces some lowering of water level at the head of the jam. These often show a rise in the lower portions of the jam indicating a movement of ice from the upper to the lower parts. Continuous moderate weather also produces openings at specially narrow points in the river. These openings, when they break out, generally show velocities in excess of 7 fet per second and in some cases velocities as high as 9 feet per second. This shows that, for a time at least, the ice deposited in a jam or gorge will resist velocities as great as 7 feet per second.

57. Plate No. 7 shows that in general the slope of an ice jam can be taken at about 1.6 feet per mile if there is no snow and very little curvature in the river,

while a slope of about 2.7 feet per mile under the same conditions will maintain with recent snowfall. This diagram also shows that if the river is so crooked that it turns 120 degrees per mile, a slope of about 3 feet per mile will be set up in ordinary winter weather by an ice jam and 4.6 feet per mile in such a reach after a snowfall. What slope would be set up if by some chance the water level at the foot of a jam should be lowered is not known and there seems to be no way of determining it.

58. The fact that open slits break out at narrow points in the river with velocities of 7 to 9 feet per second indicates that such velocities are close to the maximum to be expected under ice jams under any conditions. Further indications of the truth of this statement are given in the fact that certain power canals which operate without ice covers find velocities of about 7 feet per second much more satisfactory than velocities of 4 feet per second, because velocities of 7 feet per second prevent adherence of anchor ice to the floor of the canal.

59. In addition to the diagrams shown on plates 3 to 6 many others have been prepared which show changes in water level from day to day at various points in the jams as these form below the Lachine rapids, at Montreal, and at the foot of the Long Sault rapids and at the head of lake St. Francis. Strangely, the highest winter levels opposite Montreal are associated with warm, not cold, winters. This is due to the fact that in warm winters a channel remains open through La Prairie Basin until a late date and large amounts of ice periodically move down from there into the section below Montreal, filling that section of the river with frazil and chuck ice before the advent of spring brings down the final consignment from La Prairie Basin in the breakup period.

60. In summary, the conclusions arrived at by the Board as a result of this study may be stated as follows:—

1. Sheets of ice in the latitude of the St. Lawrence River may, under certain conditions, exert a pressure of about 22,000 pounds per linear foot of dam.
2. Smooth ice covers may be expected to form in rivers with velocities up to 1.25 feet per second in zero weather provided there is no high wind preventing such action.
3. Ice covers may be expected to pack upstream up to a velocity of 2.25 feet per second without danger of ice going under the cover.
4. Water surface slopes through ice jams on the St. Lawrence river can be taken as 1.6 feet per mile if there is no snow and 2.7 feet with recent snowfall if the stretch is comparatively straight.
5. The amount of frazil to be expected from a given area of water exposed to cooling action of air can be calculated from the following formula: Volume of ice formed per day=95 x Aver. Diff. in temperature between air and water x sq. ft. of water exposed divided by 144 x 57.4.
6. For obtaining winter slopes under ice covers formed by packing upstream, the value of "M" in the Bazin formula may be taken as 5.5 for January and 4.5 for February and March, averaged with ordinary values applicable to the stretch in question in summer, the wetted perimeter being taken as including the ice cover.

Prepared by D. W. McLachlan.

Adopted by Board, July 5, 1927.

TABLE I—ICE FORMATION CONDITIONS BETWEEN LANORAIE AND SOREL ON THE ST. LAWRENCE RIVER (SECTION TAKEN AS 110,700 SQUARE FEET AT 12·6 AT LANORAIE)

STATEMENT SHOWING CONDITIONS UNDER WHICH FRAZIL WAS CARRIED UNDER THE ICE COVER

Date	Temperature of air	Drop in water level after bridge formed	Average velocity derived from Grenville and Lock 25	Average velocity derived from Coteau and Grenville	Average velocity derived from Montreal Aqueduct and Des Prairies River
	feet	feet per sec.	feet per sec.	feet per sec.	feet per sec.
Dec. 25, 1912	+20°F.	4·2	2·56	2·60	2·57
Jan. 11, 1913	+32°F.	4·2	2·33	....	....
Jan. 9, 1913	+ 5°F.	4·2	2·40	2·43	2·31
Jan. 3, 1916	+25°F.	5·9	2·02	(Not representative)	2·27 heavy local rain
Jan. 6, 1916	+40°F.	5·9	(Not representative)	2·07	2·24+rain
Dec. 19, 1916	+14°F.	3·0	2·25	2·26	2·33
Dec. 11, 1917	0°F.	3·6	2·28	....	2·28
Jan. 4, 1919	+12°F.	3·9	2·35	2·41	2·47
Dec. 18, 1919	+10°F.	4·0	2·74	....	2·49
Dec. 17, 1924	+10°F.	2·6	2·24	2·43	2·38

STATEMENT SHOWING CONDITIONS UNDER WHICH ICE COVERS FORMED WITHOUT FRAZIL BEING CARRIED UNDER THE ICE COVER

Dec. 16, 1914	+5°F.	2·1	....	....	2·03
Dec. 27, 1920	−3°F.	1·7	2·36	....	2·28
Dec. 22, 1921	−3°F.	1·6	2·34	....	2·10

STATEMENT SHOWING CONDITIONS UNDER WHICH ONLY VERY SLIGHT AMOUNTS OF FRAZIL WERE CARRIED UNDER ICE COVER

Dec. 28, 1925	+ 9°F.	2·6	....	....	2·26
Dec. 17, 1924	+11°F.	2·6	2·24	2·43	2·38

TABLE No. 2.—STATEMENT SHOWING CONDITIONS UNDER WHICH ICE BRIDGES OR PACKS HAVE ADVANCED ON ST LAWERNCE RIVER

Location	Date	Temperature of air	Water level	Area of Section sq. ft.	Q. 1 Discnarge C.F.S.	V. Velocity in ft. per second at head of pack	Remarks
Crysler Monument	February 9, 1905	+4·2°F.	219·0	75,000	206,000	2·74	
	February 7, 1905		219·0	64·000	206,000	3·22	
Lock 23	February 13, 1905	0·4	223·7	66,000	106,000	3·12	
Doran Island				64,000	206,000	3·22	
Weavers Point	February 8, 1923	−2·0°F.	215·5	65·000	190,000	2·93	
Halfway Weavers Pt. to Bradford Pt	February 8 and 9		215·5	63,500	190,000	3·00	
Willard Creek	February 9, 1923		219·0	67,200	196,000	2·92	
Bradford Point	February 9, 1923			63,900	196,000	3·07	
Hoasic Creek	February 15, 1923	+3·0	220·0	55,000	176,500	3·22	
Lock 23	February 17, 1923	−2·3	221·5	61,600	176,000	2·86	
Cooks Point	February 8, 1923		215·5	64,400	190,000	2·95	
Cornwall Island	January 3, 1922	−2·3	156·4	66·700	187,000	2·81	
Massena Point	January 11, 1922	+9·0	168·0	65,000	181,000	2·79	
Polly's Gut	January 11, 1922		167,0	58,000	181,000	3·10	
Massena Point	February 8, 1922	+6·7	167·0	64,000	177,000	2·77	
Polly's Gut	January 21, 1922	+22·5	167·0	58,000	186,000	3·20	
4,000 ft. east of N.Y.O. railway bridge	January 29–30, 1925	− 5°F.	159·5	71·600	193,000	2·70x	
" " "	January 7	+10°F.	159·3	71,600	192,000	2·70x	
Massena Point	January 24, 1926	−10°F. on 22nd +20°F. on 23rd & 24th	169·5	67,300	163,000	2·42x	Estimated mild, average of 2 sections.
"	January 25, 1926		166·8	63,500	163,000	2·57x	Observed next day, probably O.K.
	January 17, 1925	10°F.	177·2	54,800	140,000	2·56x	Too high, some water—Barnhart Island packed through.
	February 27, 1925	7°F.	177·0	54,800	152,000	2·78	
						x	Sections appear to be about 1,000 feet too large.

TABLE No. 3.—STATEMENT SHOWING CONDITIONS UNDER WHICH ICE BRIDGES OR PACKS HAVE RECEDED ON ST. LAWRENCE RIVER

Location	Date	Temperature of air	Water level	Area of section sq. ft.	Q. Discharge C.F.S.	V. Velocity in feet per second at head of pack	Remarks
Lock 19	February 29, 1924	+28°F.	171·0	83,000	194,000	2·34	
Cornwall Island	January 29, 1924	+24°F.	159·5	70,000	188,000	2·70	
Cornwall Island	January 4, 1925	+32°F.	156·9	64,400	180,000	2·80	
Cornwall Island	January 7, 1925	+38°F.	160·0	71,000	176,000	2·45	Opened South Cornwall Island and stayed open.
Cornwall Island	January 19, 1925	− 3°F.	158·0	67,000	163,000	2·44	Stayed open.
South Cornwall Island	January 21, 1925	+25°F.	157·5	64,200	164,000	2·56	Filled a second time.
Willard Creek	April 9, 1923	....	218·5	66,200	209,000	3·16	
Lock 23	April 9, 1923	....	221·0	60,600	209,000	3·45	
Goose Neck Island	April 8, 1923	....	218·5	75,600	209,000	2·77	
Below Lock 23	April 9, 1923	....	221·0	77,000	209,000	2·72	
Below Weavers Point	April 11, 1923	....	211·0	74,900	220,000	2·94	
Head Barnhart Island	January 31, 1925	....	195·4	49,000	141,000	2·88	
Massena Point	January 28, 1924	....	171·0	69,500	174,000	2·52	
Below Lanoraie	December 11, 1886	Mild	20·9	132,000	335,000	2·52	Allows for average of 10 sections and winter retardation.
Victoria Bridge	March 31, 1925	....	44·5	140,000	352,000	2·50	Allows for winter retardation and piers of bridges.
Victoria Bridge	April 23, 1887	....	47·0	167,000	396,000	2·43	
Ile Ronde	April 25, 1887	....	40·0	152,000	405,000	2·66	Perhaps some water comes in from tributaries near La Prairie.
Moffat Island	April 1, 1925	....	45·0	160,000	352,000	2·20	
Fort St. Helen's Island	April 22, 1887	....	46·4	181,000	396,000	2·20	Breakup.

TABLE No. 4.—STATEMENT SHOWING THE AMOUNT OF FRAZIL OR SLUSH FORMED UNDER VARIOUS CONDITIONS

Place	Area exposed	Volume of frazil or slush	Degree days of freezing		Volume formed per sq. foot of exposure	
			Montreal	Ogdensburg	By actual measurement	Calculated with cooling coefficient of 95 cu. ft.
	sq. ft.	cu. ft.			cu. ft.	
Lake St. Louis, 1925	442,000,000	6,355,700,000	1,410	1,200	14·4	16·3
Lake St. Francis, 1924	460,000,000	3,721,000,000	817	738	8·1	8·45
1923	320,000,000	4,160,000,000	1,357	1,246	13·0	14·2
1922	460,000,000	3,950,000,000	1,029	890	8·5	10·3
Above foot Croil Island	190,000,000	1,394,000,000	916	826	7·33	9·5

TABLE No. 5.—STATEMENT SHOWING DEGREE DAYS OF FREEZING TO WHICH WATER SURFACES AT MONTREAL AND KINGSTON ARE EXPOSED BETWEEN THE TIMES LAKE ST. FRANCIS AND LAKE ST. LOUIS FREEZE OVER AND THE HIGHEST REACHED WATER LEVEL AT MELOCHEVILLE TAKEN AT THE END OF THE WINTER

Year	Date of freezing of Lake St. Louis (A)	Date of freezing of River at foot of Cornwall Island (B)	Date of highest water level. Head of Lake St. Louis (C)	Degree days of freezing for period A–C	Degree days of freezing for period B–C
1924—25	Dec. 16	Dec. 21	Mar. 5	M 1,410	1,200
				K 1,070	920
1923–24	Jan. 4	Jan. 21	Feb. 25	M 1,046	817
				K 777	659
1922–23	Dec. 18	Dec. 28	Feb. 28	M 1,481	1,357
				K 1,199	After Jan. 19, 916
1921–22	Dec. 22	Dec. 31	Feb. 28	M 1,240	1,029
1919–20	Dec. 22	Dec. 29	Mar. 16	M 1,606	1,535
1918–19	Dec. 20	Jan. 7	Feb. 20	M 853	582
1917–18	Dec. 15	Dec. 15	Feb. 9	M 1,672	1,672
1916–17	Dec. 29	Dec. 29	Mar. 6	M 1,458	1,458
1915–16	Dec. 20	Jan. 12	Mar. 10	M 1,285	1,013
1914–15	....	Dec. 22	Mar. 5	....	1,136
1913–14	Jan. 11	Jan. 11	Feb. 25	M 1,606	1,147
1912–13	Jan. 13	Jan. 13	Mar. 10	M 883	883
1911–12	Jan. 1	Jan. 4	Mar. 6	M 1,627	1,588
1910–11	Dec. 14	Dec. 18	Feb. 24	M 1,407	1,358
1909–10	Dec. 29	Dec. 30	Feb. 23	890	858

M = Montreal records. K = Kingston records

TABLE No. 6.—STATEMENT SHOWING AVERAGE AIR TEMPERATURE AT CERTAIN STATIONS FOR WINTER MONTHS

Fahrenheit Thermometer

Year	Month	Canton	Moira	Ogdensburg	Chezy	Montreal	Kingston	Ottawa
1923–24	Dec.	31·7	31·2	32·8	31·9	29·7	34·0	31·0
	Jan.	17·9	17·0	19·0	18·8	14·3	21·0	12·5
	Feb.	10·1	10·8	12·8	10·0	11·8	14·0	9·7
	Mean	19·9	19·7	21·5	20·2	18·6	23·0	17·7
1922–23	Dec.	21·4	18·8	23·3	21·8	18·5	24·0	17·0
	Jan.	10·8	10·7	13·2	12·2	11·2	14·0	8·0
	Feb.	9·2	7·8	10·8	10·6	9·7	13·0	6·0
	Mar.	20·6	20·1	21·7	22·2	19·2	22·0	17·2
	Mean	15·5	14·4	17·3	16·7	14·7	18·2	12·0

TABLE No. 6—STATEMENT SHOWING AVERAGE AIR TEMPERATURE, ETC.—*Concluded*

Year	Month	Canton	Moira	Ogdensburg	Chezy	Montreal	Kingston	Ottawa
1921–22	Dec	21·8	20·2	20·6	21·2	19·8	26·0	17·5
	Jan	12·8	13·3	15·6	14·2	13·2	16·0	9·5
	Feb	20·1	19·2	20·6	20·2	16·6	21·0	13·5
	March	32·0	31·8	32·0	32·6	30·6	30·0	27·5
	Mean	21·7	21·1	22·2	22·0	20·0	23·2	17·0
1920–21	Dec	23·2	22·6	24·4	24·0	22·1	27·0	20·5
	Jan	20·9	20·6	21·5	21·8	18·0	25·0	15·5
	Feb	20·9	20·6	23·2	21·2	18·9	25·0	17·0
	Mean	21·7	21·3	23·0	22·3	19·7	25·7	17·7
1919–20	Dec	21·4	18·8	23·3	21·8	16·0	20·0	12·5
	Jan	4·1	4·3	6·7	5·4	4·9	7·5	0·5
	Feb	15·4	14·8	15·6	16·0	14·5	17·0	11·0
	Mean	13·6	12·6	15·2	14·3	11·8	14·8	8·0

TABLE No. 7

Values found for V and M in Bazin's Formula

$$V = \frac{157 \cdot 6}{1 + \frac{m}{\sqrt{R}}} S^{\frac{1}{2}} R^{\frac{1}{2}} \text{ in Summer and in Winter}$$

Thickness of Ice allowed for at 2 feet

VARENNES TO LAVALTRIE—DISTANCE 85,200 FEET

—	Q Discharge C.F.S.	R Hydraulic radius	V Velocity ft. per sec.	F Fall feet	C	M
Open water—Mean flow	425,600	26·0	2·46	2·03	97·7	3·12
" High flow	508,000	29·1	2·62	1·99	100·6	3·05
" Low flow	253,000	19·6	1·94	2·09	88·1	3·46
Average open water	....	....	....	....	....	3·21
Jan. 5–7, 1925	225,720	12·6	1·34	3·94	56·5	6·34
Jan. 1–15, 1925	223,270	12·0	1·39	3·78	60·1	5·60
Jan. 16–31, 1925	197,170	11·3	1·31	3·25	63·0	5·03
Feb. 1–14, 1925	201,640	11·8	1·28	2·94	63·5	5·08
Feb. 15–28, 1925	239,710	12·8	1·40	2·75	68·9	4·61
Mar. 6–8, 1925	247,640	12·9	1·44	2·80	69·9	4·51
Mar. 1–15, 1925	253,150	13·0	1·47	2·76	71·6	4·32
Mar. 16–31, 1925	313,780	14·8	1·59	2·58	75·0	4·21
Average under ice cover	....	....	....	....	....	4·96

REPENTIGNY TO LAVALTRIE—DISTANCE 69,000 FEET

—	Q Discharge C.F.S.	R Hydraulic radius	V Velocity ft. per sec.	F Fall feet	C	M
Open water—Mean flow	425,600	25·9	2·48	1·42	107·4	2·37
" High flow	508,000	29·4	2·62	1·42	106·3	2·52
" Low flow	253,000	19·8	1·93	1·39	96·3	2·82
Average open water	....	....	....	....	....	2·57
Jan. 5–7, 1925	225,720	12·5	1·36	2·81	60·3	5·70
Jan. 1–15, 1925	223,270	12·2	1·39	2·78	62·5	5·30
Jan. 16–31, 1925	197,170	11·3	1·31	2·40	66·0	4·66
Feb. 1–14, 1925	201,640	11·9	1·28	2·12	66·9	4·68
Feb. 15–28, 1925	239,710	12·8	1·42	1·99	73·9	4·05
Mar. 6–8, 1925	247,640	13·0	1·44	2·05	72·1	4·25
Mar. 1–15, 1925	253,150	13·0	1·47	1·92	77·1	3·75
Mar. 16–31, 1925	313,780	14·8	1·59	1·82	80·3	3·69
Average under ice cover	....	....	....	....	....	4·51

TABLE No. 8

Values found for V and M in Bazin's formula

$$V = \frac{157 \cdot 6 \quad S^{\frac{1}{2}} R^{\frac{1}{2}}}{1 + \frac{m}{\sqrt{R}}} \text{ in summer and in winter}$$

Thickness of ice allowed for 2 feet

Lanoraie to Sorel—Distance = 46,000 Feet

—	Q Discharge C.F.S.	R Hydraulic radius	V Velocity feet per sec.	F Fall feet	C	M
Open Water						
Average for October, 1914	251,100	33·0	1·98	0·46	109·1	2·52
Average for October, 1915	275,500	33·3	2·15	0·52	111·0	2·43
June 10, 1919	465,100	38·9	3·10	0·74	124·0	1·68
Average for June, 1919	477,800	39·2	3·17	0·76	124·5	1·66
Average for October, 1920	261,300	33·4	2·03	0·43	114·9	2·15
Average for October, 1921	253,600	33·0	1·97	0·34	126·2	1·43
Average for October, 1922	264,600	33·3	2·07	0·46	113·5	2·26
Average for November, 1924	266,500	33·5	2·07	0·46	113·2	2·28
October 26, 1925	250,200	33·6	1·94	0·38	116·4	2·05
October 27, 1925	249,100	33·7	1·92	0·35	120·0	1·02
Average for October, 1925	253,100	33·5	1·96	0·32	128·5	1·32
Average open water						1·96
Ice Cover						
January 8, 1915	227,300	17·3	1·71	2·06	61·5	5·99
January 24, 1915	234,700	16·9	1·82	1·78	71·1	4·95
January 8, 1921	277,100	18·0	2·00	2·12	69·5	5·36
January 24, 1921	257,700	17·6	1·90	1·83	71·9	4·96
January 7, 1922	252,700	17·6	1·86	1·45	79·0	4·15
January 29, 1922	239,500	17·4	1·79	1·17	85·0	3·55
January 8, 1925	228,000	17·3	1·71	2·00	62·3	6·35
January 27, 1925	189,100	17·0	1·45	1·37	64·5	5·49
January 5, 1926	253,100	18·2	1·80	2·56	56·5	7·63
January 26, 1926	236,226	17·7	1·72	2·06	61·1	6·61
Average for January						5·51
February 23, 1915	230,000	17·2	1·74	1·74	68·2	5·41
February 9, 1921	249,200	17·1	1·09	1·60	77·5	4·27
February 28, 1921	239,200	16·8	1·85	1·28	85·5	3·45
February 22, 1922	218,800	17·7	1·60	0·96	83·2	3·75
February 10, 1925	204,400	17·8	1·50	1·61	60·1	6·82
February 24, 1925	223,800	18·6	1·56	1·59	61·5	6·16
February 9, 1926	216,100	17·3	1·62	1·72	63·6	6·15
February 27, 1926	215,100	17·7	1·58	1·75	60·9	6·68
Average for February						5·34
March 4, 1915	249,200	18·1	1·79	1·29	79·5	4·18
March 20, 1915	248,500	17·1	1·89	1·50	80·0	4·01
March 16–25, 1915	248,200	17·2	1·88	1·36	83·3	3·70
March 7, 1921	245,600	17·2	1·85	1·50	78·1	4·20
March 12–17, 1921	289,800	18·9	1·99	1·74	74·5	4·82
March 12, 1922	251,600	18·5	1·76	0·98	88·5	3·34
March 27, 1922	282,900	18·4	2·00	0·96	102·0	2·33
March 20–29, 1922	289,500	18·8	2·00	0·98	99·7	2·51
March 7, 1925	249,600	18·6	1·74	1·54	69·6	5·28
March 27, 1925	321,900	21·0	1·98	1·86	67·9	6·03
March 22–31, 1925	325,200	21·1	2·00	1·92	67·4	6·14
March 9, 1926	214,500	17·5	1·59	1·62	64·0	6·10
March 26, 1926	213,200	17·3	1·60	1·67	63·9	6·08
March 20–26, 1926	213,500	17·2	1·61	1·59	66·0	5·75
Average for March						4·61

TABLE NO. 9.—SHOWING RELATION BETWEEN SLOPE IN FEET PER MILE AND CURVATURE IN DEGREES PER MILE THROUGH ICE PACKS

No.	Station to Station	Date	Fall Feet	Distance Miles	Fall Feet Per Mile	Curvature		Remarks
						Total Degrees	Degrees Per Mile	
1	Lock 15 to Dickerson's Isd	Jan. 30, 1922	10·0	6·45	1·55	203	31·5	Mean Conditions.
2	Hd. Cornwall Isd. to Lock 15	Jan. 30, 1922	7·8	2·50	3·00	288	115·0	New Pack.
3	Hd. Cornwall Isd. to Lock 15	Feb. 16, 1922	6·1	2·50	2·40	288	115·0	Mean Conditions.
4	Ft. Barnhart Isd. to Head Cornwall Isd	Jan. 26, 1922	4·7	2·00	2·35	200	100·0	New Pack.
5	Ft. Barnhart Isd. to Head Cornwall Isd	Feb. 16, 1922	3·2	2·00	1·60	200	100·0	Mean Conditions.
6	Ft. Barnhart Isd. to Head Cornwall Isd	Feb. 27, 1922	5·5	2·00	2·75	200	100·0	Snow.
7	Ft. Barnhart Isd. to Lock 15	Feb. 4, 1922	10·5	4·60	2·30	483	105·0	Mean Conditions.
8	Ft. Barnhart Isd. to Lock 15	Jan. 30, 1922	12·5	4·60	2·72	483	105·0	
9	Robinson Bay to Hd. Cornwall Isd	Jan. 27, 1922	10·6	3·70	2·87	285	77·0	Temporary.
10	Ft. Barnhart Isd. to Lock 15	Feb. 28, 1922	11·2	4·60	2·45	483	105·0	
11	Hd. Barnhart Isd. to Lock 15	Jan. 29, 1918	35·5	8·80	4·00	826	94·0	6 inches Snow.
12	Hd. Barnhart Isd. to Lock 15	Feb. 4, 1918	17·6	8·80	2·00	826	94·0	Mean. Cold 0°F.
13	Hd. Cornwall Isd. to Lock 15	Feb. 25, 1918	9·0	2·94	3·06	335	115·0	Mean Conditions.
14	Lock 15 to Dickerson's Isd	Feb. 4, 1923	9·0	6·45	1·44	203	31·5	Mean Conditions.
15	Ft. Barnhart Isd. to Lock 15	Feb. 4, 1923	12·0	4·60	2·60	483	105·0	New Pack.
16	Ft. Barnhart Isd. to Lock 15	Feb. 9, 1923	8·7	4·60	1·89	483	105·0	Mean 19°F Conditions
17	Weaver's Pt. to Upper Farrans Pt	Feb. 9, 1923	7·4	3·60	2·05	136	38·0	New Pack.
18	Weaver's Pt. to Upper Farrans Pt	Feb. 21, 1923	5·7	3·60	1·58	136	38·0	Mean Conditions.
19	Lock 23 to Weaver's Pt	Feb. 18, 1923	9·3	6·25	1·50	325	52·0	Mean, No Snow 0°F.
20	Lock 23 to Weaver's Pt	Mar. 2, 1923	11·0	6·25	1·76	325	52·0	Snow 24°F.
21	Hd. to Ft. Cornwall Isd	Feb. 8, 1926	14·8	5·50	2·80	368	67·0	
22	Hd. to Ft. Cornwall Isd	Mar. 11, 1926	13·4	5·50	2·42	368	67·0	
23	Hd. to Ft. Cornwall Isd	Feb. 16, 1924	12·5	5·50	2·27	368	67·0	Mean, No Snow Conditions.
24	Robinson Bay to Hd. Cornwall Isd	Feb. 9, 1924	13·5	3·70	3·65	285	77·0	Snow, Temporary.
25	No. 5 to Ft. Cornwall Isd	Feb. 8, 1926	4·5	2·46	1·83	120	49·0	Mean Conditions.
26	Hd. Cornwall Isd. to Lock 15	Feb. 15, 1924	7·5	2·50	3·00	288	115·0	Mean Conditions.
27	Hd. Cornwall Isd. to Lock 15	Feb. 8, 1924	9·0	2·50	3·60	288	115·0	
28	Lock 15 to Ft. Cornwall Isd	Feb. 6, 1926	5·0	3·00	1·70	100	33·0	Mean Conditions.
29	Lock 15 to Ft. Cornwall Isd	Feb. 24, 1924	6·0	3·00	2·00	100	33·0	Mean Conditions.
30	Ft. Barnhart Isd. to Hd. Cornwall Isd	Feb. 5, 1925	4·5	2·00	2·20	200	100·0	Mean, No Snow.
31	Ft. Barnhart Isd. to Hd. Cornwall isd	Feb. 13, 1925	7·0	2·00	3·50	200	100·0	Mean, No Snow Conditions.
32	Transmission Line to Head Cornwall Isd	Jan. 19, 1925	12·0	4·40	2·73	378	86·0	New Pack.
33	Hd. Cornwall Isd. to Lock 15	Jan. 6, 1925	12·0	2·50	4·80	288	115·0	Snow.
34	Hd. Cornwall Isd. to Lock 15	Jan. 27, 1925	10·6	2·50	4·24	288	115·0	Steady Snow.
35	Ft. Barnhart Isd. to Head Cornwall Isd	Jan. 18, 1925	8·5	2·10	4·00	200	100·0	Newly formed Snow.
36	Ft. Barnhart Isd. to Head Cornwall Isd	Feb. 13, 1925	6·5	2·0	3·24	200	100·0	Thaw.
37	Ft. Barnhart Isd. to Head Cornwall Isd	Jan. 31, 1925	4·8	2·0	2·40	200	100·0	Mid-winter.
38	Hd. to foot Barnhart Isd	Jan. 31, 1925	19·0	4·7	4·00	410	87·0	Snow, Temporary.
39	Lock 23 to Upper Farrans Pt	Feb. 15, 1925	17·5	9·8	1·73	402	41·0	Cold.
40	Niagara River	Jan. 3, 1925	18·2	6·4	2·84	176	27·5	Snow.
41	Niagara River	Jan. 15, 1925	9·3	6·4	1·45	176	27·5	Cold.
42	Lock 15 to Dickerson's Isd	Feb. 6, 1925	11·4	6·45	1·77	203	31·5	
43	Lock 15 to Dickerson's Isd	Feb. 26, 1925	10·7	6·45	1·66	203	31·5	
44	Hd. to Ft. Barnhart Isd	Feb. 22, 1924	16·7	4·70	3·55	410	87·0	A few small air holes. Snow.
45	Lock 15 to "E" 8,000' East	Feb. 15, 1923	4·06	1·54	2·78	110	71·0	
46	Anderson's Ferry to Grass Isd	Feb. 15, 1922	5·8	4·20	1·38	105	25·0	
47	Anderson's Ferry to Grass Isd	Feb. 24, 1922	6·6	4·20	1·57	105	25·0	
48	Monument No. 3 to Grass Isd	Feb. 14, 1922	7·5	5·00	1·50	197	39·0	
49	Y. 3 to Ft. Cornwall Isd	Feb. 15, 1924	9·7	5·25	1·85	194	37·0	
50	Y. 3 to Ft. Cornwall Isd	Feb. 25, 1924	9·0	5·25	1·71	194	37·0	
51	Hd. to Ft. Pollys Gut	Feb. 21, 1924	3·5	1·29	2·72	146	113·0	
52	Hd. to Ft. Pollys Gut	Feb. 8. 1924	6·7	1·29	5·20	146	113·0	Snow.
53	Hoasic Cr. to Strawberry Isd	Feb. 18, 1923	5·9	3·20	1·84	210	66·0	
54	Hoasic Cr. to Strawberry Isd	April 9, 1923	8·0	3·20	2·50	210	66·0	Prescott ice 23·5 F. Day before 33·9°F.
55	Lock 1 to Vickers	Feb. 9, 1913	7·20	4·00	1·80	84	21·0	
56	Lock 1 to Vickers	Feb. 15, 1916	8·8	4·00	2·20	84	21·0	
57	Lock 1 to Longue Pointe	Dec. 28, 1924	9·0	5·60	1·60	106	19·0	
58	Lock 1 to Vickers	Feb. 4, 1913	11·0	4·00	2·75	84	21·0	New Pack.
59	No. 3 to No. 5 Sth. Cornwall Isd	Jan. 25, 1926	8·4	2·30	3·65	145	63·0	Snow.
60	No. 3 to No. 5 Sth. Cornwall Isd	Feb. 8, 1926	6·4	2·30	2·80	145	63·0	Mean Conditions.
61	Hd. Pollys Gut to No. 3	Jan. 29, 1926	7·0	1·80	3·90	146	81·0	Snow.
62	Hd. Pollys Gut to No. 3	Feb. 8, 1926	4·0	1·80	2·20	146	81·0	Mean conditions.

TABLE NO. 10.—TABLE SHOWING DETERMINATION OF RATE OF HEAT LOSS IN EXPOSED WATER SURFACE DURING COLD WEATHER BETWEEN VARIOUS STATIONS ON THE ST. LAWRENCE RIVER—YEARS 1924 AND 1925

Station to Station	Date passing Upper Station	Time of passage — Days	Upper Water Temp.	Lower Water Temp.	"M" Mean of Water Temp's.	"D" Diff. of Water Temp's.	Centre date of period — Days	"T" Mean Air Temp's.	"M"—"T"	River Area between Stations — 1,000sq.ft.	River Volume between Stations — 1,000cu.ft.	River Discharge 1,000 cu.ft. per day	Formula for "C" in Br. Ther. Units	Value of "C"	Mean Value of "C"
Kingston to Brockville.	Dec. 1924	9·787													
	7, 12:01 a.m.	....	40·82	35·43	38·12	5·39	11·89	27·80	10·3	4,873,600	176,830,000	18,067,000	62·4 x V x D	120·7	
	10, 12:01 a.m.	....	41·00	33·62	37·31	7·38	14·89	19·80	17·5	....	....	....	———	97·4	97·6
	13, 12:01 a.m.	....	39·67	32·79	36·23	6·88	17·89	14·90	21·3	....	....	....	9·787 x A x (M-T)	97·6	
Kingston to North Channel.	Nov. Dec. 1924	10·940													
	30, 12:01 a.m.	....	42·70	38·50	40·60	4·20	5·45	30·95	9·65	5,314,000	198,800,000	18,230,000	62·4 x V x D	93·1	
	3, 12:01 a.m.	....	41·40	37·50	39·45	3·90	8·45	32·00	7·45	....	....	....	———	111·9	108·9
	6, 12:01 a.m.	....	40·60	35·20	37·90	5·40	11·45	28·40	9·50	....	....	....	10·9 x A x (M-T)	121·7	
North Channel to Massena Pt.	Dec. 1924	0·793													
	10, 10:20 a.m.	....	38·66	37·72	38·19	0·94	10·83	19·65	18·54	602,600	14,300,000	18,020,000	62·4 x V x D	94·5	
	14, 9:28 a.m.	....	37·10	34·92	36·10	2·18	14·79	3·23	32·74	....	....	....	———	124·5	101·9
	18, 8:49 a.m.	....	34·68	33·60	34·14	1·08	18·77	10·80	23·34	....	....	....	0·793 x A x (M-T)	86·6	
Massena Point to Soulanges.	Dec. 1924	1·630													
	3, 9:21 p.m.	....	38·90	36·80	37·85	2·10	4·70	22·75	15·10	1,993,500	29,765,000	18,260,000	62·4 x V x D	79·6	79·3
	10, 9:50 a.m.	....	37·90	35·55	36·70	2·35	11·22	19·70	17·00	....	....	....	1·63 x A x (M-T)	79·0	
Kingston to Cardinal.	Dec. 1925	11·00													
	7, noon	....	40·30	34·75	37·50	5·55	13·00	24·05	13·45	5,403,600	206,202,000	18,000,000	62·4 x V x D	85·8	
	10, noon	....	38·50	34·00	36·25	4·50	16·00	26·00	10·25	....	....	....	———	91·4	92·6
	13, noon	....	38·00	32·90	35·45	5·10	19·00	24·90	10·55	....	....	....	11·0 x A (M-T)	100·5	
Kingston to Massena Point.	Dec. 1925	11·850													
	6, 12:01 a.m.	....	40·50	34·30	37·40	6·20	11·92	25·55	11·85	5,917,000	212,085,000	17,900,000	62·4 x V x D	98·8	
	10, 12:01 a.m.	....	38·70	34·05	36·35	4·65	15·92	25·75	10·60	....	....	....	———	83·0	91·9
	14, 12:01 a.m.	....	37·75	32·50	35·10	5·25	19·92	24·60	10·50	....	....	....	11·85 x A x (M-T)	93·8	
Massena Point to Soulanges.	Dec. 1925	1·634													
	13, 1:44 p.m.	....	35·65	32·70	34·15	2·95	14·39	18·60	15·55	1,994,000	29,516,000	18,060,000	62·4 x V x D	107·5	
	15, 4.57 a.m.	....	35·00	32·60	33·80	2·40	16·02	17·45	16·35	....	....	....	———	83·2	99·8
	16, 8:10 p.m.	....	34·50	32·00	33·25	2·50	17·66	20·25	13·00	....	....	....	1·634 x A x (M-T)	108·8	
													Mean..........	....	96·0

APPENDIX F

EXPERIMENTS ON STRENGTH OF ICE

McGill University,
Montreal, Que., May 20, 1926.

To D. W. McLachlan, Esq.,
Chairman, Canadian Section, Joint Board of Engineers,
St. Lawrence Waterways Project,
317 West Block, Ottawa, Ont.

Sir,—I have the honour to submit the following report *on tests to determine the physical properties of ice at different temperatures.*

GENERAL

The tests herein described were made under general instructions received from you, and were carried out during the months of February and March, 1926, at the Cold Storage Warehouse of the Harbour Commissioners of Montreal, where rooms which could be kept at uniform temperatures ranging from 0° F. to 32° F., were available. A supply of river ice of excellent quality was obtained through the City Ice Co., of Montreal, from their ice cutting field in the LaPrairie basin of the St. Lawrence river, off Verdun. It was noticeably free from flaws, cracks, air bubbles or foreign material, and the upper layer of white ice was only about one inch thick. The blocks were cut under special supervision and handled with the greatest care during transportation to the warehouse so as to avoid risk of damage, and were stored in a room at a temperature of about 30° F. where the necessary specimens were prepared for test. It was proposed to carry out tests at different temperatures, and as the work of cutting specimens could be carried out more conveniently at a temperature near the freezing point than at a temperature near zero, it was decided to cut and store all specimens at about 30° F., removing them to other rooms at lower temperatures as required for testing. It was found later that ice splinters considerably when sawn at temperatures near to 0° F. but at 30° F. the sawing was accomplished with comparatively little difficulty. A series of special mitre boxes was made by which compression specimens 5 inches by 5 inches by 5 inches and 5 inches by 5 inches by 10 inches, and beams 3 inches by 2 inches by 50 inches long were prepared, using ordinary carpenters saws and planes, on the rough specimens cut with ice saws from the larger blocks. (See blueprint attached). All specimens were marked to denote the direction of the crystals.

OBJECTS OF TESTS

The primary object of the tests was to determine the behaviour of ice at different temperatures when compressed normally to the crystals, as may occur under natural conditions above dams, power houses, bridges and such structures. The deformation of the ice was to be measured by the use of mirror extensometers, and its elastic properties and strength determined. Tests were to be made also on beams, to find the modulus of rupture and the modulus of elasticity,

"E", by observation of the deflection under load. The scope of the tests could not be defined in advance, as the field of investigation and method of compression testing proposed were new, very little information having been published regarding the properties of ice at different temperatures.

The complete series of tests includes the following:—

(*a*) Compression tests at about 30°F., 16°F. and 3°F. with definite load increments corresponding to about 10 pounds per square inch applied at regular time intervals ranging from 5 seconds to 320 seconds.

(*b*) Crushing strength of ice at the above temperatures under loads applied uniformly, and suddenly.

(*c*) Observations on the continuous yielding of ice in compression at about 30°F. under loads as low as 20 pounds per square inch.

(*d*) The yielding of ice in compression at 14°F. under sustained loads of different intensities from 100 pounds per square inch to 400 pounds per square inch.

(*e*) Bending tests at about 30°F. and 16°F. at four different rates of loading.

(*f*) Miscellaneous tests.

APPARATUS USED

The apparatus used was loaned from the Strength of Materials Laboratory at McGill University, and included an Olsen Testing Machine of 10,000 pounds capacity, Martens' Mirror Extensometers, Telescopes and Scales, for compression tests; apparatus for supporting beams for bending tests, weights, deflection scales and sundry minor accessories.

The Martens' Extensometer was adopted on account of its peculiar adaptability to such tests, experience in the laboratories at McGill University having demonstrated its sensitiveness and accuracy. Two Extensometers were used in each compression test, being held against opposite faces of the specimens. (See blueprint.) To provide bearing for the sharp edges of the Extensometer, flat pieces of galvanized iron about $\frac{1}{2}$ inch square with small projecting points soldered to them, were pressed by hand against the faces of the specimens and frozen in place. This arrangement proved entirely satisfactory. Some initial difficulty in maintaining the Extensometers in place without slipping was overcome by stretching a heavy rubber band over four vertical bars screwed into the base of the testing machine outside the four corners of the specimen, and placing short pieces of wood between the Extensometer bars and the stretched rubber band, so as to exert a pressure between the Extensometers and the ice block. The gauge length of the Extensometers was 2 inches, and a change of 0.001 inch produced a movement of one main scale division, or ten small divisions, amounting to 0.5 inch, on the scale. Readings were made, as usual, by telescope, fractions of the small scale divisions being easily estimated. Each main scale division corresponds to a compression of 0.001 inch, and an estimated division to 0.00001 inch, so that a strain of $\frac{1}{200{,}000}$ could be measured. The yielding on opposite faces of compression specimens of materials such as concrete, stone, etc., is rarely the same, and the mean of a number of readings taken around the specimen is essential if a proper measure of deformation is to be obtained. In the tests described, two Extensometers were used, and the mean of the two readings was used to determine the yielding. From these mean readings curves showing the relation between deformation and load can be plotted, and the properties of the ice determined.

To secure uniform bearing and load distribution a heavy iron plate with planed faces was slightly warmed above room temperature and passed over the loading faces so as to melt the ice slightly. The resulting moisture was wiped off and the block set on a thin sheet of blotting paper placed on the lower loading faces of the machine. The heavy iron plate was then placed on the upper face of the block, and a steel washer was inserted between it and another plate directly under the upper loading face. When a small compressive load (250 pounds) had been applied, shims were placed between the two plates. The loading was then continued as required. The load was uniformly distributed by this means. The tool marks of the loading plate could be seen clearly on the blocks after a test was over, and the print of the circular marks on the lower face of the testing machine provided for centering the specimens were also transferred completely to the paper under the block. Details of these arrangements are shown in the attached blueprint.

CONTINUOUS YIELDING OF ICE UNDER SMALL PRESSURES

After the preliminary work necessary in finding suitable means of securing Extensometers and loading the blocks as noted above, tests were made on the recovery of the ice when compression was applied and removed. A block 4.9 inches by 4.9 inches by 4.65 inches high was loaded at 28° F. with 250 pounds sustained for five minutes and there was complete recovery on removal of the load. After second and third applications of this load, sustained as before, recovery was not complete. The shortening in the latter cases was 0.00005 inch in 2 inch gauge length, and 0.00002 inch remained on removal of the load. A load of 500 pounds was then applied and sustained 3 minutes during which time the shortening increased from 0.00006 inch to 0.00008 inch, and 0.00003 inch remained on removal of the load. There was thus a definite "creep" of the Extensometers, and permanent set, at this small load of about 20 pounds per square inch. A similar condition was found with a load of 750 pounds and it was decided to observe the behaviour of a block under a sustained load of 500 pounds. The results are shown in plate 1. It will be seen that the block yielded continuously for 3 hours 30 minutes, the load intensity being 20.8 pounds per square inch. The yield is shown for both sides of the block. On one side the total was 0.00182 inch of which only 0.00009 inch, about 5 per cent, was recovered when the load was removed. On the other side the total yield was 0.00047 inch, and recovery 0.00005 inch—about 10 per cent. The ice is therefore "plastic" under very small load at this temperature, viz. 29° F. As the block yielded, the screws operating the loading head had to be turned slightly to maintain the floating lever of the testing machine in mid position. Movement had practically ceased when the test ended, one extensometer showing no change during the last 15 minutes, and the other a change of 0.00001 inch only in that time. Readings were taken every 5 minutes and were very regular. The deformations were noticeably different on the two sides. The mean of the two is taken as measuring the deformation due to the load. This continued yielding is evidently of the greatest importance in considering the question of ice pressure against structures. If the mean total deformation, 0.00023 inch, during the first 10 minutes be used in computing the modulus of elasticity (E), it would be $\dfrac{20.8 \text{ pounds per square inch by 2 inches}}{0.00023 \text{ inch}} = 180{,}800$ pounds per square inch whereas if the mean total deformation of 0.00114 inch during the whole 3 hours 30 minutes to be used, E would be 36,500 pounds per square inch. The value of E corresponding to the mean total deformation during

the first minute in which the load was sustained, was 489,000 pounds per square inch. As already noted, the block recovered only very slightly when the load was removed.

STANDARD METHOD OF LOADING IN COMPRESSION TESTS

The results of the test just described showed that it was necessary to adopt some standard rate of loading, as the movements of the extensometers due to any load increment will depend largely on the length of time during which the load is sustained before readings are taken. It was decided to apply the load in all cases in increments of 250 pounds. One operator moved the balance weight along the beam, while another operator kept the beam floating by rotating the screws of the machine. Extensometer readings were taken at different time intervals, there being one observer for each extensometer. Four persons were thus employed on each test, one of the machine operators giving the time signals to those reading the extensometers, and then adding load as soon as the readings were taken. In this way readings were made as follows:—

At temperatures 28° F. to 30° F.—Intervals of 5, 10, 20, 40 and 80 secs.
At temperatures 14° F. to 16° F.—Intervals of 5, 10, 20, 40, 80 and 160 secs.
At temperatures 3° F.—Intervals of 5 and 320 secs.

The reasons for making tests at 3° F. at only two loading rates were (*a*) that less importance was attached to tests at this temperature than at the higher temperatures; (*b*) that time was limited, and the tests were intended primarily to determine whether the general conclusions drawn from the more extended series of tests at the higher temperatures would be supported by tests at the lower temperature. For these reasons the longer intervals of loading were used, and the tests bore out the conclusions already reached.

DIRECTION OF APPLIED LOAD, AND DETERMINATION OF MODULUS OF ELASTICITY

The loads were applied normally to the axis of the crystals, this being the direction in which pressure would act in a natural ice cover. The ice is not elastic except for extremely small loads, and as the loading progressed at any one rate, the deformation corresponding to a given load increment was found to increase. It follows that strictly speaking, there is no definite modulus of elasticity, and that values of E calculated from the deformations resulting from successive increments of load, as if the deformations were elastic, will decrease as the loading progresses. Furthermore, as the deformation under any load increases as the load is sustained, the values of E corresponding to any given range of load will decrease as the length of the loading interval increases.

In order to obtain comparative results the following standard procedure was adopted:—

The loading block was shimmed as described above when the load was 250 pounds. All specimens were approximately 5-in. by 5-in., so that 250 pounds load corresponds to about 10 pounds per square inch. Most of the specimens were approximately cubes, but a few were about 10 inches long. These were noted in the Tables. The determinations in the 2 inch gauge lengths corresponding to successive increments of 1,000 pounds applied in four equal amounts of 250 pounds with time intervals as noted, were found, and values of E calculated from the mean increments. By plotting these values as ordinates on a base line

representing 1st, 2nd, 3rd, etc., increments of 1,000 pounds the variations of E, both with *stage* of load and with *rate* of loading, can be easily seen. The results of the tests at different temperatures are now submitted, after which notes are given of the general behaviour of the blocks.

COMPRESSION TESTS AT 28°F. TO 30°F.

(a) Modulus of Elasticity—E

Plate 2 shows the results at the different loading rates, and it will be seen that apart from the running together of the curves for 20 sections and 40 sections rates at the higher loads, the values of E are progressively lower as the time interval of loading increases, and as the actual load increases. Each point plotted represents the average of 7, 8 or 9 tests, as will be seen from Tables of actual deformations in each test, and of average deformations quoted later on Pages 15-18. From these tables it is clear that at the higher loads the deformations in individual tests, depart more from the average for all tests, than they do at the lower loads. This may explain in part the overlapping of curves as noted above as the ice "flows" more rapidly as the intensity of loading increases. It should be emphasized that the averages of *all* completed tests are shown. No process of selection was used. Occasionally tests failed, as for example by displacement of extensometers due to local cracking of the ice, but the only tests rejected were for these or similar reasons. These remarks apply to tests made at all temperatures, and to both compression and bending tests. While therefore the actual values of E might be altered somewhat if a larger number of tests could have been made at each rate of loading, it is improbable that the changes would be great, and that the general laws of variation would be invalidated. Tests at the lower temperatures gave similar results, and served to emphasize the extreme importance of the time factor.

(b) General Behaviour under Test—Compressive Strength—Recovery after Load.

The blocks were remarkably clear and free from flaws—so clear that ordinary book print could be easily read through them. The first outward signs of yielding occurred at loads from 2,500 pounds to 5,000 pounds. They were both audible and visible, and the term "crackling" was applied to them. Suddenly a slight noise would be heard, and one or more spots of a slaky appearance would develop in the block. These appeared to be due to breakdown between the crystals, and spread gradually, through the block. When they became numerous, the block was no longer transparent, but was described as "clouded." During this stage the blocks yielded fairly rapidly, and the compression head had to be kept moving to preserve the weighing beam in the floating position. This was described as "following." Had the loading been maintained without further increment after "clouding" was well developed, the yielding would have been both continuous and rapid, but the predetermined rate of loading was maintained, and the ice "flowed" continuously. Sometimes the loadings were continued up to the capacity of the machine, 10,000 pounds, but no value can be assigned for the compression strength of ice under such conditions, as owing to the flow (even at the 5 seconds loading rate) the area under load was continuously increasing. Blocks originally 5 inches by 5 inches would flow beyond the edges of the loading plate, 6 inches square, and a length of 5 inches was frequently and rapidly reduced to about 3½ inches under sustained high load at the end of a test. When specimens failed under such conditions the pieces showed a tent-like appearance, the horizontal crystals piling up to form a ridge parallel to the loaded faces.

In tests made at lower temperatures the deformations were not so great, and the recovery was noted when the load was reduced to zero after reaching the capacity of the machine. At the temperature of 28°F. to 30°F. at which the first series of tests was carried out, the clouded appearance of the blocks, and the large deformations showed that recovery would be negligibly small. In many cases the blocks crushed after becoming thoroughly clouded, but as stated above no compressive strength can be quoted on account of the "flow" of the ice.

COMPRESSION TESTS AT 14°F. TO 16°F.

Modulus of Elasticity and General Behaviour: Plate 3 shows the results of tests similar to those described in detail for temperature 28°F to 30°F. They are the averages of from 6 to 8 tests at each loading rate, and show the same characteristic with regard to the time influence as was shown at the higher temperature. The values of E corresponding to a particular stage of a given loading rate are higher than at 28°F. to 30°F., and the curve for the 5 seconds and 10 seconds loading rates are practically straight lines.

At these loading rates the ice "crackled" as at the higher temperature, but to a lesser extent and generally at higher loads, so that in general the blocks were not clouded—when the maximum load of 10,000 pounds was reached None of the blocks failed under that load and only when the load was removed did they become clouded—faintly and fairly uniformly as a rule. The appearance of the blocks was very noticeably different from that at the higher temperatures, and it was only at the slower rates of loading that the characteristic behaviour noted at all loading rates at 28° F. to 30° F. was found.

At these slower rates of loading the blocks were clouded during application of the load, and on removal of load the recovery was much less than in the tests at the 5 seconds and 10 seconds loading rates. (See tables on page 19 to 21). There is some overlapping or apparent irregularity in the curves for 40 seconds and 80 seconds loading rates, after loads of 4,000 pounds to 5,000 pounds were reached. It must be remembered that this is the stage at which deformations are considerable, and that the average of 6 or 8 tests only is available. The curve for the 160 seconds loading rate falls well below all the others, and bearing in mind the nature of the material and the limitations regarding the number of tests made, the results generally are reasonably consistent. Special reference is made on Page 25 to yielding of blocks at 14° F. to 16° F. under sustained loads of different intensities. A load of about 200 pounds per square inch—which is approximately that to which reference has just been made—may be a critical load, and the point will be discussed further. The values of "E" for small loads seem to be of the same order for all loading rates up to 40 seconds, the curves being bunched irregularly, for the first 1,000 pounds increment of load. This is perhaps not surprising. Deformations at these loads are much more nearly elastic than at higher loads, and are small. For loads longer maintained, greater deformations result, as the ice has a greater tendency to flow. Values of "E" for the first 1,000 pound load increment are about 1,000,000 pounds per square inch for loading rates up to 40 seconds but for the loading rates of 80 seconds and 160 seconds the values drop to 700,000 pounds per square inch and 500,000 pounds per square inch respectively.

The general evidence of these results is the same as that found from tests at 28° F. to 30° F.:—That the value of "E" decreases as the load increases, for all rates of loading; and that for any given range of loading, the value of "E" decreases as the length of the loading interval increases. Furthermore, the corresponding "E" values are higher at 14° F. to 16° F. than at 28° F. to 30°

F. Thus for the 7th increment of 1,000 pounds (corresponding to a stress intensity of about 280 pounds square inch) and a loading rate of 5 seconds for 250 pounds, "E" is 450,000 pounds square inch at 14° F. and 150,000 pounds square inch at 28° F. Values of "E" at 14° F. for the loading rate of 160 seconds are consistently higher than those at 28° F. for a loading rate of 80 seconds. Other comparisons substantiating the general conclusions drawn are readily made from the Plates, and are strengthened by the results of tests made at 3° F. as described below.

COMPRESSION TESTS AT 3° F.

Modulus of Elasticity and General Behaviour. Tests were made at two rates of loading: 5 seconds for 250 pounds and 320 seconds for 250 pounds and the results are shown in Plate 4. The curve for the former rate is approximately a straight line, the values of "E" differing but slightly from those at 14° F. The general behaviour was similar to that of the specimens tested at the same loading rate at 14° F., but at the loading rate of 320 seconds the characteristic "flowing" took place, as had been anticipated, and values of "E" are much lower than at the 5 seconds rate. They are, however, much higher than corresponding values, at 14° F. In fact, the curve for a loading rate of 160 seconds at 14° F. is almost the same as that for the loading rate of 320 seconds at 3° F. The figures for the 5 seconds rate are the averages of 7 tests, those at 320 seconds rate being the averages of 5 tests. These results confirm the conclusions already drawn from the other tests. The time factor is the all-important quantity at all temperatures.

TABLES SHOWING DEFORMATIONS OF COMPRESSION BLOCKS REFERRED TO ABOVE

The following tables are submitted in detail to emphasize the general results already given, and to show how widely the deformations vary, particularly at the higher loads. The departure of individual readings from the group averages is much greater at high loads than at low loads, and at 30° F. than at 14° F. or 3° F., and yet the averages point clearly to the well-defined laws enumerated. The increase of deformation for each successive load increment of 1,000 pounds at any particular loading rate and temperature is clearly seen, as also the increase in deformation with lengthening loading interval for corresponding load increments. These comparisons are facilitated by the Summary Table on page —. It may be worth pointing out that the readings given are the deformations in a 2-inch gauge length corresponding to definite ranges of load. Owing to minor variations in the sizes of the blocks, the stress intensities for these ranges are not the same in all cases, so that a comparison of the deformations of any two blocks is not a true comparison of the values of " E ". A general comparison is, however, both valid and instructive.

N.B.—In the tables, the deformations in a gauge length of 2 inches, corresponding to a successive load increments of 1,000 pounds are shown, the unit of deformation being $\frac{1}{1000}$ of an inch. The initial load was 250 pounds in all cases.

28° F. TO 30° F.

5 sec. Rate — Deformations in 2″ gauge length — Unit =0·001″

Load Incr. of 1,000 lb.	Specimen Number							Average
	10	11	35+	36	45	46	49+	
1st	0·085	0·060	0·115	0·100	0·060	0·055	0·135	0·087
2nd	0·110	0·100	0·160	0·111	0·110	0·100	0·150	0·120
3rd	0·165	0·150	0·205	0·125	0·180	0·130	0·200	0·165
4th	0·275	0·165	0·260	0·160	0·375	0·200	0·300	0·249
5th	0·465	0·215	0·350	0·170	0·520	0·275	0·365	0·337
6th	0·575	0·320	0·515	0·195	0·725	0·355	0·495	0·454
7th	0·975	....	1·530	0·245	0·950	0·490	0·765	0·708
8th	1·645	....	....	0·285	1·330	....	1·030	....
9th	2·405	....	....	0·295	2·070	....	....	....
Size of Specimen, Inches	4·96 x 5·00	4·95 x 5·00	4·85 x 4·85	4·90 x 5·05	5·00 x 5·02	4·97 x 5·00	4·86 x 4·86	

10 Sec. Rate. — Deformations in 2″ gauge length — Unit=0·001″

Load Incr. of 1000 lb.	Specimen Number								Average
	13	27	30	32+	38	39	40	48+	
1st	0·180	0·105	0·090	0·145	0·100	0·115	0·080	0·800	0·112
2nd	0·270	0·125	0·170	0·180	0·100	0·180	0·080	0·110	0·152
3rd	0·410	0·160	0·360	0·245	0·120	0·220	0·250	0·125	0·236
4th	0·550	0·270	0·590	0·310	0·160	0·500	0·545	0·145	0·384
5th	0·780	0·530	0·725	0·665	0·200	0·695	0·825	0·175	0·574
6th	0·960	0·840	0·795	1·080	0·215	1·185	0·950	0·195	0·777
7th	1·275	1·385	1·050	1·765	0·275	2·020	1·075	0·215	1·133
8th	1·825	2·670	1·645	4·410	0·355	3·385	1·055	0·260	....
9th	2·870	5·105	3·225	....	0·815	5·750	1·000	0·300	
Size of Specimen, Inches	4·90 x 4·90	4·90 x 5·00	4·90 x 4·93	4·95 x 5·00	5·00 x 5·03	5·00 x 5·00	4·98 x 5·02	4·87 x 4·91	
Per cent recovery	....	....	....	....	....	....	....	49	

+Specimens noted thus were approximately 10″ high, all others being approximately 5″ high.

28° F. TO 30° F.

20 Sec. Rate — Deformations in 2″ gauge length — Unit=0·001″

Load Incr. of 1,000 lb.	Specimen Number								Average
	14	16	29	34+	41	42	43	47+	
1st	0·110	0·120	0·140	0·135	0·220	0·220	0·185	0·090	0·153
2nd	0·180	0·170	0·260	0·335	0·465	0·335	0·275	0·135	0·269
3rd	0·260	0·285	0·455	0·700	0·785	0·475	0·445	0·180	0·448
4th	0·395	0·440	0·965	1·335	1·155	0·575	0·580	0·245	0·711
5th	2·140	0·575	1·585	2·535	1·650	0·670	0·800	0·295	1·281
6th	2·400	0·685	2·555	5·295	2·305	0·865	1·370	0·410	1·986
7th	7·715	0·875	4·530	....	3·700	1·800	2·560	0·605	....
8th	....	1·040	10·990	....	....	4·620	6·700	1·520	....
9th	....	1·295	....	....	....	14·50	....	....	
Size of Specimen, Inches	4·94 x 5·00	4·84 x 4·90	4·90 x 5·00	4·90 x 4·93	4·95 x 5·05	4·96 x 5·05	5·00 x 4·90	4·95 x 4·95	

28° F. to 30° F.

40 Sec. Rate — Deformations in 2″ gauge length — Unit=0·001′

Load Incr. of 1,000 lb	Specimen Number 50	51	52	163	164	165	166	167	168	Average
1st	0·230	0·400	0·120	0·105	0·185	0·125	0·195	0·105	0·085	0·172
2nd	0·465	0·935	0·260	0·185	0·360	0·240	0·335	0·235	0·150	0·352
3rd	0·595	1·465	0·380	0·335	0·595	0·340	0·535	0·380	0·240	0·541
4th	0·675	2·385	0·545	0·460	0·815	0·425	0·880	0·615	0·280	0·787
5th	0·710	5·215	0·675	0·630	1·145	0·470	1·705	1·080	0·340	1·330
6th	0·795	....	0·850	0·665	1·925	0·515	3·815	1·710	0·880	....
7th	0·875	....	1·135	1·080	4·840	0·630	14·78	3·380	4·350	....
8th	1·025	....	1·410	2·180	22·13	0·685	....	11·37	....	
9th	1·225	....	1·835	9·280	....	0·970	....	....	....	
Size of Specimen, Inches	5·00 x 5·02	4·89 x 4·97	4·98 x 4·98	4·98 x 5·00	4·90 x 5·00	4·95 x 5·06	4·93 x 5·00	4·97 x 4·99	4·92 x 5·05	
Per cent recov'd	....	....	....	....	....	26	....	....	....	

+Specimens noted thus were approximately 10″ high, all others being approximately 5″ high.

80 Sec. Rate — Deformations in 2″ gauge length — Unit=0·001″

Load Incr. of 1,000 lb.	Specimen Number 169	170	171	172	173	174	175	Average
1st	0·160	0·175	0·130	0·215	0·145	0·245	0·195	0·181
2nd	0·465	0·330	0·385	0·545	0·270	1·165	0·475	0·505
3rd	1·095	0·465	1·035	1·015	0·455	1·400	0·700	0·881
4th	2·105	0·605	2·675	1·685	0·745	2·125	1·100	1·579
5th	4·675	0·810	5·810	3·545	1·425	4·900	1·580	3·249
6th	....	1·005	....	15·45	3·485	....	3·520	....
7th	....	1·415	....	....	....	....	14·27	....
8th	....	4·155	....	....	....	....	....	
Size of Specimen, Inches	4·93 x 5·00	5·01 x 5·03	4·87 x 5·00	4·99 x 5·02	4·97 x 4·98	4·97 x 5·04	4·98 x 5·01	

Summary of Tests at 28° F. to 30° F.

Loading Rate	Average of Deformations due to 1st 1,000	2nd 1,000	3rd 1,000	4th 1,000	5th 1,000	6th 1,000	7th 1,000
5 secs	0·087	0·120	0·165	0·249	0·337	0·454	0·708
10 secs	0·112	0·152	0·236	0·384	0·574	0·777	1·133
20 secs	0·153	0·269	0·448	0·711	1·281	1·986	....
40 secs	0·172	0·352	0·541	0·787	1·330	....	
80 secs	0·181	0·505	0·881	1·579	3·249	....	

This summary table shows how the deformation corresponding to any given range of load increases as the loading rate becomes longer, and how the deformation corresponding to equal successive increments of load increases as the load increases, at any prescribed loading rate.

14° to 16° F.

5 Sec. Rate — Deformations in 2″ gauge length — Unit =0·001″

Load incr. of 1,000 lb.	Specimen Number 70	71	72	73	74	75	85+	87+	Average
1st	0·080	0·080	0·085	0·105	0·075	0·085	0·080	0·090	0·085
2nd	0·080	0·090	0·105	0·105	0·105	0·090	0·090	0·110	0·097
3rd	0·100	0·120	0·110	0·120	0·125	0·090	0·090	0·120	0·109
4th	0·110	0·125	0·130	0·130	0·155	0·110	0·100	0·130	0·124
5th	0·120	0·135	0·145	0·150	0·205	0·120	0·115	0·160	0·139
6th	0·145	0·170	0·045	0·170	0·180	0·125	0·125	0·190	0·139
7th	0·165	0·195	0·020	0·195	0·290	0·135	0·150	0·215	0·171
8th	0·190	0·140	0·070	0·225	0·315	0·170	0·170	0·265	0·193
9th	0·230	0·240	0·005	0·275	1·135	0·165	0·215	0·305	0·321
Size of Specimen, Inches	4·95 x 5·00	4·91 x 5·00	5·02 x 5·03	4·95 x 4·95	4·90 x 5·00	4·87 x 5·00	4·91 x 4·96	4·91 x 4·93	
Per cent Recovery	70·0	67·0	95·0	31·0	49·5	77·5	58·8	65·8	64·3

10 Sec. Rate — Deformations in 2″ gauge length — Unit=0·001

Load Incr. of 1,000 lb.	Specimen Number 67	68	69	76	77	78	84+	88+	Average
1st	0·055	0·115	0·060	0·065	0·100	0·065	0·130	0·100	0·086
2nd	0·075	0·140	0·080	0·080	0·115	0·085	0·180	0·115	0·109
3rd	0·080	0·180	0·125	0·090	0·115	0·105	0·255	0·155	0·138
4th	0·110	0·210	0·150	0·070	0·145	0·135	0·330	0·175	0·166
5th	0·120	0·270	0·165	0·095	0·170	0·145	0·485	0·220	0·209
6th	0·135	0·235	0·180	0·080	0·195	0·165	0·690	0·275	0·244
7th	0·120	0·275	0·200	0·130	0·230	0·185	0·880	0·340	0·295
8th	0·120	0·565	0·375	....	0·270	0·205	1·205	0·495	0·462
9th	0·180	0·765	0·900	....	0·315	0·250	1·590	0·665	0·666
Size of Specimen, Inches	5·00 x 5·00	4·88 x 4·93	4·97 x 4·98	4·85 x 4·98	4·85 x 4·88	4·89 x 4·91	4·93 x 4·94	4·93 x 4·94	
Per cent Recovery	....	26·0	27·7	....	62·6	63·9	10·8	39·3	38·4

+Specimens noted thus were approximately 10″ high, all others being approximately 5″ high.

20 Sec. Rate — Deformations in 2″ gauge length — Unit=0·001″

Load Incr. of 1,000 lb.	Specimen Number 64	65	66	80	81	82	83+	89+	Average
1st	0·100	0·115	0·070	0·075	0·085	0·095	0·110	0·090	0·093
2nd	0·130	0·110	0·135	0·090	0·140	0·105	0·130	0·120	0·120
3rd	0·120	0·255	0·245	0·135	0·185	0·140	0·180	0·140	0·175
4th	0·130	0·455	0·445	0·165	0·255	0·180	0·215	0·190	0·254
5th	0·175	0·680	0·730	0·190	0·330	0·385	0·285	0·225	0·375
6th	0·240	0·800	0·790	0·210	0·550	0·530	0·380	0·260	0·470
7th	0·285	....	0·885	360	0·830	0·685	0·475	0·295	0·545
8th	0·350	....	1·120	0·645	1·140	1·095	0·655	0·320	0·761
9th	0·370	....	1·780	0·975	1·810	1·480	0·905	0·370	1·100
Size of Specimen, Inches	4·90 x 4·93	4·93 x 4·97	4·93 x 4·97	5·00 x 5·00	4·94 x 5·00	4·85 x 5·00	4·95 x 4·97	4·87 x 4·87	
Per cent Recovery	52·5	....	....	19·4	23·6	18·3	30·8	70·6	30·7

14° F. TO 16°F.

40 Sec. Rate — Deformations in 2″ gauge length — Unit=0·001″

Load Incr. of 1,000 lb.	Specimen Number							Average
	90	91	92	115	127	128	129	
1st	0·030	0·150	0·110	0·060	0·200	0·110	0·065	0·103
2nd	0·060	0·260	0·220	0·095	0·320	0·210	0·075	0·177
3rd	0·065	0·405	0·320	0·165	0·475	0·355	0·100	0·269
4th	0·095	0·495	0·410	0·210	0·660	0·520	0·105	0·356
5th	0·340	1·085	7·10	0·465	0·870	0·790	0·140	
6th	0·785	2·355	0·780	....	1·230	1·350	1·555	
7th	2·185	4·375	1·650	1·760	2·305	2·090	0·185	
8th	6·065	11·56	2·285	....	5·615	4·225	0·205	
9th	....	....	4·645	....	15·77	10·30	0·220	
Size of Specimen, Inches	4·93 x 5·02	4·87 x 5·05	5·00 x 5·02	5·00 x 5·00	4·99 x 5·00	5·00 x 5·00	4·98 x 5·02	
Per cent Recovery	....	....	2·2	....	....	....	72·0	

80 Sec. Rate — Deformations in 2″ gauge length — Unit=0·001″

Load Incr. of 1,000 lb.	Specimen Number							Average
	126	130	131	132	149	150	152	
1st	0·125	0·140	0·060	0·155	0·200	0·080	0·175	0·134
2nd	0·205	0·200	0·125	0·245	0·310	0·190	0·215	0·213
3rd	0·270	0·230	0·170	0·400	0·440	0·230	0·220	·2800
4th	0·380	0·275	0·265	0·535	0·560	0·270	0·225	0·359
5th	0·420	0·285	0·290	0·590	0·635	0·335	0·195	0·392
6th	0·545	0·310	0·355	0·555	0·660	0·400	0·225	0·436
7th	0·935	0·215	0·450	0·585	0·755	0·560	....	0·583
8th	1·460	0·265	3·545	0·685	0·915	0·665	2·630	1·024
9th	2,470	1·100	0·825	0·775	0·980	0·955	5·340	1·065
Size of Specimen, Inches	4·83 x 5·05	4·94 x 5·04	4·90 x 4·97	4·96 x 4·97	4·91 x 4·93	4·92 x 5·00	4·93 x 5·02	
Per cent Recovery	13·3	18·8	32·0	12·0	25·0	39·5 ..	......	23·5

160 Sec. Rate — Deformations in 2″ gauge length — Unit=0·001″

Load Incr. of 1,000 lb.	Specimen Number						Average
	133	151	+153	154	158	159	
1st	0·080	0·185	0·400	0·195	0·175	0·135	0·195
2nd	0·130	0·370	0·635	0·400	0·340	0·355	0·372
3rd	0·185	0·545	0·860	0·675	0·455	0·670	0·532
4th	0·250	0·845	1·130	0·975	0·550	1·265	0·669
5th	0·255	1·120	1·680	2·400	0·555	4·845	1·809
6th	0·270	2·270	4·435	....	0·460	....	
7th	0·325	7·510	....	14·19	1·385	....	
8th	0·320	....	....	....	9·455	....	
9th	0·385	....	....	....	....	....	
Size of Specimen, Inches	4·90 x 4·91	4·89 x 4·94	4·97 x 4·99	5·00 x 5·02	4·93 x 5·03	5·00 x 5·02	
Per cent Recovery	28·2	....	....	....	....	....	

+Specimens noted thus were approximately 10″ high, all others being approximately 5″ high.

SUMMARY OF TESTS AT 14° F. TO 16° F.

Loading Rate	Average of Deformations due to								
	1st 1,000	2nd 1,000	3rd 1,000	4th 1,000	5th 1,000	6th 1,000	7th 1,000	8th 1,000	9th 1,000
5 secs....................	0·085	0·097	0·109	0·124	0·139	0·139	0·171	0·193	0·321
10 secs....................	0·086	0·109	0·138	0·166	0·209	0·244	0·295	....	
20 secs....................	0·093	0·120	0·175	0·254	0·375	0·470	....	....	
40 secs....................	0·103	0·177	0·269	0·356	0·629	....	....	....	
80 secs....................	0·134	0·213	0·280	0·359	0·392	0·436	0·583	1·024	1·065
160 secs....................	0·995	0·372	0·532	0·669	1·809	....	....	....	

This table shows the same general results as those noted already at 28° F. to 30° F. There is, however, some irregularity in the deformations at the 80-seconds rate. These increase continuously for successive load increments, but the deformations for the 5th and 6th thousands of load do not fit in with the general law shown by the other columns as read vertically, being less than those noted at the 40-seconds rate. Whether this is the chance result of averages or not cannot be stated definitely, but it may be noted that it occurs at a loading stage (about 200 pounds per square inch) at which certain peculiarities seem to arise very frequently. Reference will be made to this later, when considering the effect of sustained loads of different intensities at this temperature. The reduction in the rate at which deformation increases as the loading increases is so marked at the 5-seconds loading rate that the average for the 6th thousand of load is the same as for the 5th thousand.

2° F. TO 3° F.

5 Sec. Rate — Deformations in 2″ gauge length. — Unit=0·001″

Load Incr. of 1,000 lb.	Specimen Number							Average
	182	184	185	186	187	188	189	
1st..............................	0·080	0·110	0·080	0·105	0·060	0·070	0·075	0·083
2nd..............................	0·070	0·115	0·075	0·110	0·075	0·085	0·070	0·086
3rd..............................	0·085	0·125	0·095	0·125	0·090	0·085	0·110	0·102
4th..............................	0·085	0·130	0·095	0·185	0·105	0·095	0·105	0·114
5th..............................	0·110	0·140	0·115	0·210	0·125	0·125	0·130	0·136
6th..............................	0·110	0·185	0·140	0·370	0·150	....	0·140	0·183
7th..............................	0·150	0·470	0·145	0·530	0·315	....	0·120	0·288
8th..............................	0·130	0·295	0·180	0·355	0·200	....	0·045	0·201
9th..............................	0·150	0·200	0·185	1·530	0·340	....	0·170	0·429
Size of Specimen, Inches........	4·95 x 5·02	4·96 x 4·96	4·95 x 4·96	4·87 x 5·00	4·92 x 4·96	4·93 x 5·00	4·93 x 4·98	
Per cent Recovery..............	68·0	73·0	70·0	....	41·0	....	66·0	63·6

320 Secs. Rate — Deformations in 2″ gauge length — Unit=0·001″

Load Incr. of 1,000 lb.	Specimen Number					Average
	196	197	201	202	203	
1st..	0·115	0·235	0·245	0·220	0·120	0·187
2nd..	0·190	0·485	0·480	0·375	0·290	0·364
3rd..	0·215	0·825	0·795	0·500	0·355	0·538
4th..	0·245	1·160	1·170	0·630	0·460	0·733
5th..	0·355	2·160	1·965	0·690	0·720	1·178
6th..	0·475	5·300	2·705	0·980	1·375	2,167
7th..	0·515	....	......	1·520	....	
8th..	0·680	....	....	....	....	
9th..	2·050	....	....	....	....	
Size of Specimen, Inches..........................	4·92 x 4·98	4·94 x 4·97	4·87 x 4·95	4·93 x 4·98	4·95 x 4·95	
Per cent Recovery..............................	....	....	....	....	....	....

These results show the same characteristics as were found at the higher temperatures. Deformations (average) increase progressively as the loading increases at the 5 seconds and 320 seconds loading rates, and are much greater at the latter than at the former. There is some irregularity at about 8,000 pounds load at 5 seconds, similar to that noted at 14° F. to 16° F. at loads of 5,000 pounds to 6,000 pounds. The deformations are noticeably less for the 8th thousand than for the 7th in five cases out of six, and this effect is well marked in the average column. It is possible that there is a critical stress at about this load at this temperature, and that such a critical stress exists at all temperatures well below 32° F., increasing in value as the temperature is reduced. The evidence of the above tests, and of others, at sustained loads at 14° F. to 16° F. tends to support such a view.

SUMMARY OF COMPRESSION TESTS AT DIFFERENT LOADING RATES AT TEMPERATURES RANGING FROM ABOUT 30° F. TO 3° F.

The results of the above tests are conveniently summarized for comparison in the following table. Average deformations of all tests under each particular condition are tabulated, firstly for different loading rates at a given temperature, and secondly for the same loading rates at different temperatures. Apart from the irregularities at certain loads referred to above, the deformations at any given temperature and stage of loading increase as rate of loading becomes slower, and at any given loading rate they decrease at any given stage of loading as the temperature drops.

Deformations in 2″ Gauge Length
Unit=0·001″

Loading Rate Secs.	Increments of 1,000 lbs. load									Temp.
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	
5	0·087	0·120	0·165	0·249	0·337	0·454	0·708	...	...	
10	0·112	0·152	0·236	0·384	0·574	0·777	1·133	...	...	28° F
20	0·153	0·269	0·448	0·711	1·281	1·986	...	...	...	to
40	0·172	0·352	0·541	0·787	1·330	...	...	...	...	30° F
80	0·181	0·505	0·881	1·579	3·249	...	...	...	...	
5	0·085	0·097	0·109	0·124	0·139	0·139	0·171	0·193	0·321	
10	0·086	0·109	0·138	0·166	0·209	0·244	0·295	...	...	14° F
20	0·093	0·120	0·175	0·254	0·357	0·470	...	...	...	to
40	0·103	0·177	0·269	0·356	0·629	...	...	...	...	16° F
80	0·134	0·213	0·280	0·359	0·392	0·436	0·583	1·024	1·065	
160	0·195	0·372	0·532	0·669	1·809	...	...	...	...	
5	0·083	0·086	0·102	0·114	0·136	0·183	0·288	0·201	0·429	2° F
320	0·187	0·364	0·538	0·733	1·178	2,167	...	...	...	to 3° F
5	0·087	1·120	0·165	0·249	0·337	0·454	0·708	...	...	28° F
5	0·085	0·970	0·109	0·124	0·139	0·139	0·171	0·193	0·321	14° F.
5	0·083	0·086	0·102	0·114	0·136	0·183	0·288	0·201	0·429	2° F
10	0·112	0·152	0·236	0·384	0·574	0·777	1·133	...	...	28° F
10	0·086	0·109	0·138	0·166	0·209	0·244	0·295	...	...	14° F
20	0·153	0·269	0·448	0·711	1·281	1·986	...	...	...	28° F
20	0·093	0·120	0·175	0·254	0·357	0·470	...	...	...	14° F
40	0·172	0·352	0·541	0·787	1·330	...	...	...	...	28° F
40	0·103	0·177	0·269	0·356	0·629	...	...	...	...	14° F
80	0·181	0·505	0·881	1·579	3·249	...	...	...	...	28° F
80	0·134	0·213	0·280	0·359	0·392	...	...	...	...	14° F

The great deformations at 28° F. as compared with those under corresponding conditions at 14° F. are very obvious, as also is the fact that the deformations at 28° F. increase much more as the rate of loading becomes slower than do the corresponding deformations at 14° F. *These results are of great significance in considering the pressure which ice can exert against such structures as dams.*

DEFORMATIONS UNDER SUSTAINED LOADS AT 14° F. TO 16° F.

A series of tests was made to determine the deformation under sustained compressive loads of different intensities, ranging from about 100 pounds per square inch to 400 pounds per square inch. The load required to produce these conditions was applied in all cases at the rate of 250 pounds per 5 seconds, and the deformations then read at regular intervals under sustained load, the weighing beam of the testing machine being kept floating by rotating the screws as the blocks yielded. The mean of the readings of two extensometers was taken, as in all previous tests, and the curves showing deformations plotted against the time during which the loads were sustained are very regular. (See Plate 5.) Only a sufficient number of points are plotted to enable curves to be drawn. All deformations were measured in 2-inch gauge length.

A load of 103 pounds per square inch maintained for 3½ hours caused a total deformation of 0·0016 inches, and a load of 300 pounds per square inch caused a total deformation of 0·022 inches in about 8 minutes. The curve for a load of 400 pounds per square inch could not be plotted on the same time scale, being practically coincident with the deformation axis. The form of the curves for loads of 103 pounds per square inch and 300 pounds per square inch suggested that there might be some particular load intensity for which the curve would be a straight line, and several tests were made to investigate this point. Curves are shown for load intensities of 150, 175, 190 and 198 pounds per square inch. It will be seen that these curves fall in regular order, and that there is a large field open between the curves for 190 pounds per square inch and 198 pounds per square inch. This is specially interesting in view of the results already noted in the tests under loads applied at different rates, when it was found that deformations per 1,000 pounds of load increment were frequently less for, say, the 6th thousand than for the 5th thousand. This peculiarity or irregularity was generally observed at a load of about 200 pounds per square inch and the sustained load tests showed that for load intensities of this order the informations vary greatly. Thus at 190 pounds per square inch the total deformations in 1½ hours was 0·0066 inches, and at 198 pounds per square inch it was 0·027 inches in about 45 minutes. Reference to the tables for progressive loading at different rates at this temperature shows that the deformations for the higher loads varied very greatly, the departure of individual readings from the average being distinctly greater, at large loads than at small loads. The curves shown for sustained loads are for single tests only, but it is improbable that the regular order in which they lie is the result of chance. The evidence points towards the view that at a load intensity of about 200 pounds per square inch the ice is in a critical condition. There may be some inter-crystalline slip or cleavage at this load, followed by yielding of very variable rate, which cannot be predicted from the appearance of the ice as seen by the eye. It is also interesting to note that the modulus of rupture found from the beam tests described later was of the order of 200 pounds per square inch.

Irregularities in the deformation per 1,000 pounds of load increment were also noted at 3° F., but at higher loads. No sustained load tests were possible at this temperature, but it may well be that there is a critical load at this temperature, of a higher value than that suggested by the tests at 14° F.

BENDING TESTS—MODULUS OF ELASTICITY AND MODULUS OF RUPTURE

A number of bending tests were made at the same temperatures as in the compression tests described above, and at different loading rates. In all cases the beams were approximately 3 inches wide by 2 inches deep, and the span was 41 inches. Glass or brass bearing plates were placed between the beam and the supports to distribute the pressure, and the load was applied in increments of 1 pound at each of two loading sections 14 inches from the supports. Half-round wooden-bearing blocks were placed across the beam, and cords were passed over the top and notched ends of these, being kept vertical and close to the faces of the beam by wooden spacing bars at a convenient distance below the beam. A cord attached to the centre of the spacer bars carried a circular piece of wood on which the slot weights were placed, to load the beams. The supports were carried on a heavy lathe bed, on which was set a telescope by which the central deflections were read on a small steel scale attached to the face of the beam by freezing in place under a small pressure. The deflections were estimated to 0·001 inches. (The general arrangement is shown in the blue print at the beginning of the report.)

Preliminary tests showed that the recovery was not complete even for very small loads, and that the deflection increased continuously over long periods under sustained load. It was decided to make the tests at different loading rates, the procedure being as follows:—

After the zero reading of the scale had been taken, each of two operators added 1 pound load at his stirrup, and the deflection was read say 5 seconds later. Similar loads were added and deflections read every 5 seconds until the beam broke. Tests were made in the same way with loading intervals of 10, 20 and 40 seconds at temperatures approximately 14°F. and 28°F. Time did not permit making tests at 3° F.

In all cases the deflections per pound increment of load increased as the loading proceeded, so that values of the modulus of elasticity computed for successive stages of loading would show continuously decreasing values. Approximations to the form of the load-deflection curves were made by drawing two straight lines, representing the first and second stages of loading, the latter extending to the point of fracture. This was deemed to be sufficient, as the results cannot be compared as simply as those for the compression tests. In the latter the blocks were all approximately 5 inches by 5 inches, so that deformations due to a given load were comparable. But in the case of the beams, the specimens could not be prepared so easily to a definite size, and variations in breadth and depth, particularly the latter, affect the stress due to any given load. All the beams broke suddenly and fracture occurred at or near the loading point. The modulus of rupture and values of "E" corresponding to the two stages of loading defined above were computed for all beams, and the results are shown in the tables appended, and in plates 6 and 7. Tests were made with crystals horizontal and vertical, the average of three tests being given, except in cases where only two tests were made.

Examination of the results shows in general:—

(1) That values of "E" are somewhat greater when the crystals are vertical than when they are horizontal.

(2) That values of "E" are greater at 14°F. than at 28°F. under similar conditions.

(3) That values of "E" decrease as the load increases under all conditions and generally as the length of the loading time interval increases for both stages of loading.

(4) That the modulus of rupture is about the same value for crystals horizontal and crystals vertical, but is much greater at 14°F. than at 28°F., the average of all tests at these temperatures being 226 pounds per square inch and 171 pounds per square inch respectively.

(5) That the modulus of rupture does not vary much at the different loading rates.

Other comparisons may appear from a study of the results, but it is worth suggesting that there may be a connection between the modulus of rupture and the load intensity at which certain peculiarities were noted, particularly at 14°F., during the compression tests. These have also been referred to in describing the results of tests at 14°F. under sustained loads, and the evidence suggests that a critical condition, possibly related to inter-crystalline displacements, exists at a load intensity of about 200 pounds per square inch. The average modulus of rupture for 24 beams at this temperature was 226 pounds per square inch.

In the compression tests at 28°F. to 30°F. the deformation increased continuously for successive load increments of 1,000 pounds. There were no cases similar to those at 14°F., in which the actual deformations for certain of the later increments of load were less than those for earlier increments. But the tables show that in many cases, such for example as Specimens 36, 45 and 49 at the five seconds loading rate (page 16), the *increases* in the deformations per 1,000 pounds of added load were less between the 4th and 5th thousands than between the 3rd and 4th. The average modulus of rupture of 21 beams was 171 pounds per square inch, which corresponds to a load of about 4,250 pounds on a 5-inch by 5-inch cube.

This distinct lagging in the deformations at higher loads was noted also in some of the compression tests at 3°F., and occurred at higher loads than those at which it was noted at 14°F. No beam tests were made at 3°F., so that modulus of rupture values are not available, but the evidence so far as it goes is consistent and interesting. Tests on the compressive or crushing strength of ice showed that it becomes greater as the temperature is lowered. (See page 441.) This also is consistent with the results just described.

BEAM TESTS AT TEMPERATURES FROM 28°F. TO 30°F.

Test No.	B	D	Crystals	First Stage: Bending stress	First Stage: —	Second Stage: Modulus of rupture	Second Stage: —	1 lb. load at each stirrup in
	ins.	ins.		lb. per sq. in.	E lb. per sq. in.	lb. per sq. in.	E lb. per sq. in.	
98.........	2·89	1·97	Hor........	84·5	836,000	167	555,000	
99.........	2·99	1·99	"	81·8	745,000	190	622,000	5 secs.
			Mean.......	83·0	790,000	178	588,000	
18.........	2·90	1·90	Vert........	81·0	750,000	177	429,000	
19.........	2·90	1·95	"	101·0	602,000	200	316,000	
20.........	3·00	1·95	"	61·0	670,000	134	462,000	5 secs.
			Mean.......	81·0	674,000	170	402,000	
96.........	2·89	1·86	Hor........	76·2	686,000	160	386,000	
97.........	2·92	1·93	"	94·0	533,000	187	330,000	10 secs.
			Mean.......	85·0	610,000	173	358,000	
21.........	2·86	1·93	Vert........	72·0	790,000	143	566,000	
22.........	2·90	1·90	"	105·0	682,000	210	423,000	
23.........	2·90	1·92	"	79·5	780,000	158	450,000	10 secs.
			Mean.......	85·5	751,000	170	480,000	

N.B.—All beams were supported freely on a span of 41 inches, and loaded equally at sections 14 inches from each support. E was computed from the central deflection.

BEAM TESTS AT TEMPERATURES FROM 28°F. TO 30°F.—*Continued*

Test No.	B	D	Crystals	First Stage: Bending stress	First Stage: —	Second Stage: Modulus of rupture	Second Stage: —	1 lb. load at each stirrup in
	ins.	ins.		lb. per sq. in.	E lb. per sq. in.	lb. per sq. in.	E lb. per sq. in.	
94.........	3·00	1·93	Hor........	69·6	473,000	129·5	247,000	
95.........	2·99	1·98	"	81·0	427,000	138·5	256,000	
			Mean.......	75·3	450,000	134·0	251,000	20 secs.
24.........	2·92	1·95	Vert........	100·0	640,000	229·0	434,000	
25.........	2·90	1·95	"	116·0	830,000	306·0	579,000	
26.........	3·04	1·94	"	83·0	513,000	193·0	227,000	
			Mean.......	100·0	661,000	243·0	413,000	20 secs.
176.........	2·86	1·93	Hor........	87·3	415,000	158·0	164,000	
177.........	2·90	1·86	"	84·5	335,000	135·0	163,000	
178.........	2·97	1·93	"	77·8	315,000	131·0	150,000	
			Mean.......	83·2	355,000	141·0	159,000	40 secs.
179.........	2·85	1·98	Vert........	99·4	218,000	197·0	127,000	
180.........	2·83	1·95	"	71·5	473,000	126·0	191,000	
181.........	2·98	1·85	"	75·3	531,000	133·0	239,000	
			Mean.......	82·1	441,000	152·0	186,000	40 secs.

N.B.—All beams were supported freely on a span of 41 inches, and loaded equally at sections 14 inches from each support. E was computed from the central deflection.

BEAM TESTS AT TEMPERATURES FROM 14°F. TO 16°F.

Test No.	B	D	Crystals	First Stage		Second Stage		1 lb. load at each stirrup in
				Bending stress	—	Modulus of rupture	—	
	ins.	ins.		lb. per sq. in.	E lb. per sq. in.	lb. per sq. in.	E lb. per sq. in.	
61........	2·89	1·90	Hor........	113·5	690,000	210·0	582,000	
63........	3·00	1·75	"	119·0	975,000	232·0	695,000	
140........	2·92	1·96	"	129·0	866,000	253·0	770,000	5 secs.
			Mean.......	127·0	844,000	232·0	682,000	
62........	2·91	1·84	Vert........	94·5	877,000	205·0	713,000	
141........	2·89	1·90	"	113·5	787,000	178·0	692,000	
142........	2·85	1·93	"	112·0	761,000	191·0	660,000	5 secs.
			Mean.......	107·0	808,000	191·0	688,000	
137........	2·90	1·87	Hor........	115·5	721,000	266·0	614,000	
58........	2·89	1·96	"	84·5	685,000	213·0	541,000	
59........	2·88	1·94	"	94·0	637,000	172·0	472,000	10 secs.
			Mean.......	95·0	681,000	217·0	542,000	
60........	2·89	1·92	Vert........	119·0	874,000	237·0	643,000	
138........	2·85	1·95	"	102·0	672,000	203·0	554,000	
139........	2·78	1·86	"	104·0	714,000	209·0	490,000	10 secs.
			Mean.......	108·0	753,000	216·0	562,000	

N.B.—All beams were supported freely on a span of 41 inches, and loaded equally at sections 14 inches from each support. E was computed from the central deflection.

BEAM TESTS AT TEMPERATURES FROM 14°F. TO 16°F.—*Continued*

Test No.	B	D	Crystals	First Stage		Second Stage		1 lb. load at each stirrup in
				Bending stress	—	Modulus of rupture	—	
	ins.	ins.		lb. per sq. in.	E lb. per sq. in.	lb. per sq. in.	E lb. per sq. in.	
55........	2·90	1·90	Hor........	101·0	586,000	209·0	299,000	
134........	2·88	1·97	"	136·5	598,000	256·0	387,000	
135........	2·90	2·00	"	125·0	692,000	219·0	524,000	20 secs.
			Mean.......	121·0	625,000	228·0	403,000	
56........	2·94	1·85	Vert........	107·0	670,000	201·0	400,000	
57........	2·86	1·87	"	93·0	637,000	202·0	345,000	
136........	2·89	1·99	"	112·0	653,000	222·0	447,000	20 secs.
			Mean.......	104·0	653,000	208·0	397,000	
143........	2·86	1·96	Hor........	109·0	526,000	246·0	352,000	
144........	2·96	1·96	"	121·0	608,000	301·0	424,000	
145........	2·84	2·01	"	105·0	710,000	296·0	522,000	40 secs.
			Mean.......	112·0	615,000	281·0	432,000	
146........	2·90	1·95	Vert........	93·0	566,000	230·0	274,000	
147........	2·91	1·90	"	105·0	712,000	177·0	465,000	
148........	2·91	1·93	"	100·0	948,000	311·0	558,000	40 secs.
			Mean.......	99·0	742,000	240·0	432,000	

N.B.—All beams were supported freely on a span of 41 inches, and loaded equaliy at sections 14 inches rom each support. E was computed from the central deflection.

COMPRESSION OR CRUSHING STRENGTH OF ICE

The tests described above show that the term "compression or crushing strength of ice" is meaningless in itself. The behaviour of ice in compression is different at the same rates of loading at different temperatures, and at different rates of loading at the same temperature. The time-factor is the all important quantity. To obtain characteristic compression fractures the load must be applied rapidly, so that the ice has no opportunity to "flow", and tests were made at different temperatures with this principle in mind. After preliminary experimenting it was found that two operators, one moving the balance weight along the lever and the other rotating the screws of the machine, could apply the load continuously, at the rate of 1,000 pounds in 2 seconds. This was the most rapid rate which could be controlled, and was adopted as a standard. In some cases the blocks did not fail under 10,000-pound load (approximately 400 pounds per square inch) applied at this rate, and tests were made in which, the balance weight having been set at a given reading, the screws were rotated as rapidly as possible so as to apply the load quickly. Sometimes the blocks carried 400 pounds per square inch applied in $1\frac{3}{5}$ seconds and in other cases the blocks failed before the beam floated, so that the load carried was not known. When the 5 inch by 5 inch blocks did not fail at the full capacity load of the machine, smaller specimens were cut from other 5 inch by 5 inch blocks and tested at the standard loading rate. A summary of tests made at temperatures about 14° F, 2° F, and 28° F is appended, this being the order in which tests were made.

14°F.

LOADS APPLIED AT RATE OF 1,000 POUNDS IN 2 SECONDS NORMALLY TO CRYSTALS

Number	Size	Maximum load	Pound per square inch at failure	Remarks
	inches	lb.		
101	4·90 x 4·94	10,000	Not fail	Faint crackling 8,250 pounds. Flowing under maximum load.
102	5·02 x 5·01	10,000	"	Crackling, medium clouding when load was removed.
103	4·82 x 5·00	10,000	"	Crackling. Heavy clouding with 10,000 pounds sustained.
104	4·78 x 5·00	10,000	"	Light clouding upper part after unloading.
107	4·87 x 4·96	10,000	"	Faint crackling.
113	4·45 x 4·49	10,000	"	"
116	3·99 x 4·00	10,000	"	Loud crackling. Load 625 pounds per square inch.
117	4·00 x 4·16	10,000	"	Loud crackling. Load 600 pounds per square inch.
119	3·06 x 3·39	7,250	672	Typical compression failure.
120	3·41 x 3·37	3,250	282	" "
121	3·41 x 3·39	8,250	715	" "

NOTE.—All specimens were approximately 5 inches high. Numbers 119, 120 and 121 were cut from the same block.

14°F.

LOADS APPLIED SUDDENLY (TIMES AS STATED) NORMALLY TO CRYSTALS

Number	Size	Pound per Maximum load	square inch at failure	Time	Remarks
	inches	lb.		secs.	
105..........	4·78 x 5·00	10,000	Not fail	3·2	Load applied suddenly 7 times.
105..........	4·78 x 5·00	10,000	"	3·0	No sign of failure. Slightly clouded on
105..........	4·78 x 5·00	10,000	"	2·4	removal of load.
105..........	4·78 x 5·00	10,000	"	1·8	The block has been loaded previously to
105..........	4·78 x 5·00	10,000	"	1·4	10,000 pounds at standard rate.
105..........	4·78 x 5·00	10,000	"	1·4	Number 104 in table above.
105..........	4·78 x 5·00	10,000	"	1·4	
106..........	4·98 x 5·00	10,000	"	1·4	Faint uniform clouding upper part.
107..........	4·87 x 4·96	10,000	"	1·2	Tested previously at standard rate. Much clouding under sustained maximum load.
113..........	4·45 x 4·49	10,000	501	2·0	Tested previously at standard rate. Typical compression failure.
118..........	4·04 x 4·08	8,250	502	1·4	Typical compression failure.
122..........	4·98 x 5·02	10,000	Not fail	1·2	This block had been used in sustained load tests, 150 pounds per square inch. (Plate 5). Cleavage plane developing from top to bottom and parallel to crystals.

Note.—All specimens were approximately 5 inches high.

LOADS APPLIED AT RATE OF 1,000 POUNDS IN 2 SECONDS. 2°F.

Number	Size	Load to crystals	Maximum load	Pound per square inch at failure	Remarks
	inches		lb.		
190.......	2·98 x 2·96	Normal	8,500	963	Typical fracture. Like tent with ridge.
+191.......	2·95 x 3·00	"	6,500	735	Conical. Split from top to bottom.
+192.......	2·92 x 2·95	"	5,750	617	" "
193.......	2·95 x 3·00	Parallel	8,250	932	" "
194.......	2·94 x 2·96	"	6,750	776	" "
195 ..	2·93 x 2·93	"	10,000	Not fail Over 1,165	Cleavage planes developing.
198.......	2·97 x 3·00	Normal	5,000	561	Typical failure. Like tent with ridge.
199.......	2·91 x 2·85	"	7,250	874	" "
200.......	2·99 x 3·00	"	9·250	1,030	" "

N.B.—All specimens were approximately 5 inches high.

Specimens 191 and 192 probably had crystals parallel to load. Types of fracture were quite distinct for the two cases. All original blocks 5 inches by 5 inches were carefully marked to show direction of crystals, and in cutting these down to ensure failure at loads within the capacity of the machine, some error may have arisen. Blocks were brittle and difficult to saw without chipping at this low temperature.

BLOCKS AT 28°F. 1,000 POUNDS IN 2 SECONDS

Number	Size	Load to crystals	Maximum load	Pound per suqare inch at failure	Remarks
	inches		lb.		
204.........	4·86 x 5·03	Normal	10,000	Not fail	Crackling at 2,250 pounds.
205.........	5·00 x 5·00	"	10,000	"	Clouded.
206.........	4·04 x 4·06	"	5,250	320	Clouded and flowed very rapidly.
207.........	4·03 x 4·06	"	3,500	214	Typical fracture. Flowed rapidly.
208.........	3·92 x 4·03	"	4,750	300	Typical fracture. Ridge parallel to crystals.
209.........	3·95 x 4·15	"	5,000	305	" " "
210.........	3·93 x 4·05	"	4,350	273	" " "
211.........	4·05 x 5·10	Parallel	6,800	329	Typical fracture. Conical.
212.........	4·00 x 4·00	"	4,000	250	" "
213.........	3·98 x 4·03	"	10,000	Not fail	
215.........	5·00 x 5·00	Normal	8,000	320	Typical fracture. Ridge parallel to crystals.
216.........	5·00 x 5·00	"	9,750	390	" " "
217.........	4·82 x 4·84	"	10,000	Not fail	

LOADS APPLIED SUDDENLY. TIMES AS STATED. 28°F.

204.........	4·86 x 5·03	Normal	10,000 in. 1·2 secs.	409	Load applied immediatly after standard loading in table above. (Ridge fracture.) Table above.
213.........	3·98 x 4·03	Parallel	8,000 in. 1·2 secs.	498	Conical fracture.
217.........	4·82 x 4·84	Normal	8,000 in. 1 sec.	343	Table above. Ridge fracture.

N.B.—All specimens were approximately 5 inches high.

Most of the tests were made with the load normal to the crystals, but a few were included with the load parallel to the crystals. In the former, the typical failure was tent-like, the horizontal crystals forming a ridge parallel to the loaded faces, while in the latter distinctly conical fractures resulted. There appears to be little difference between the strengths at failure under these two conditions, and there was considerable variation in results at each temperature.

At 28° F. the average ultimate strength of nine specimens which failed under the standard rate of loading was 300 pounds per square inch. Three others which had not failed under the standard rate of loading were broken immediately afterwards by suddenly applied loads, the average strength being 417 pounds per square inch. The load in two cases was of less intensity than had been sustained previously.

At 14° F. the loads carried were higher than at 28° F. none of the specimens measuring approximately 5 inches by 5 inches failing at a load of 10,000 pounds even when this was applied suddenly. One specimen No. 105, withstood this sudden load seven times after being loaded previously to 10,000 pounds at the standard rate. Of three specimens Nos. 119, 120 and 121 which failed at the standard rate of loading, No. 120 failed unaccountably at a much lower load than the other two. All were cut from the same block. The mean of the two higher results is 693 pounds per square inch, which compares rationally with 600 pounds per square inch and 625 pounds per square inch for Nos. 116 and 117 respectively, these being loads which did not cause failure. Of six blocks tested under suddenly applied loads, only two failed, at approximately 500 pounds per square inch.

At 2° F. eight out of nine blocks tested failed under the standard loading rate, and the average ultimate strength was 811 pounds per square inch. The other block, with crystals vertical, carried over 1,165 pounds per square inch applied at the standard rate without failure. The strengths were approximately the same for both conditions of loading.

The tests show that the crushing strengths of the given blocks loaded at the rate of 1,000 pounds in 2 seconds were as follows:—

Temp. °F.	Crushing strength, lb./sq. in.
28	300
14	693
2	811

For other loading rates different figures would be obtained. It has been shown that the time element is probably the greatest factor in determining the pressure of ice against a structure. Conclusions drawn from the crushing strength alone are of no value. The crushing strength itself at any given temperature depends on the rate of loading.

MISCELLANEOUS TESTS

Weight of Ice.—By measuring and weighing a block of ice approximately 5 inches by 5 inches by 10 inches at a temperature of 28° F., the weight per cubic foot was found to be 57.4 pounds. This figure was used in the calculations for the modulus of rupture in the beam tests.

Deflection of Beam under Small Sustained Loads. A beam 2.90 inches wide by 1.95 inches deep was loaded on a span of 41 inches by equal weights placed 14 inches from each support, as in the tests for modulus of rupture. Each load was 4 pounds and the bending stress, including that due to the beam itself and the stirrups, was about 55 pounds per square inch. The deflections were read at intervals for several days, and on the first day the recovery when the load was removed was observed for about 4¾ hours. There was about 0.025 inch recovery in a total deflection of 0.158 inch and under sustained load the deflection increased steadily to 0.585 inch in 6 days when the test was stopped. The temperature during the test was from 28° F. to 30° F. The following table shows the results:—

Date	Hour	Load at each loading point	Deflection in inches
February 19	5.55 p.m.	Stirrup only	0·000 (datum)
	5.55 p.m.	Stirrup and 4 lbs.	0·002
February 20	10.00 a.m.	"	0·158
	10·05 a.m.	Stirrup only	0·145
	10.15 a.m.	"	0·134
	11.30 a.m.	"	0·133 Steady
	1.15 p.m.	"	0·132 Steady
	2.45 p.m.	"	0·133 Steady
	2.50 p.m.	Stirrup and 4 lbs.	0·141
February 22	2.00 p.m.	" "	0·349
	4.45 p.m.	" "	0·358
February 23	10·15 a.m.	" "	0·418
	1.15 p.m.	" "	0·428
	4.00 p.m.	" "	0·435
February 24	10.00 a.m.	" "	0·490
	1·00 p.m.	" "	0·500
	4·30 p.m.	" "	0·509
February 25	9.00 a.m.	" "	0·567
	noon	" "	0·572
	4.00 p.m.	" "	0·585

Deflection of Beams under their Own Weight. Two beams approximately 3 inches wide by 2 inches deep were supported side by side with their ends free, and allowed to bend under their own weight.

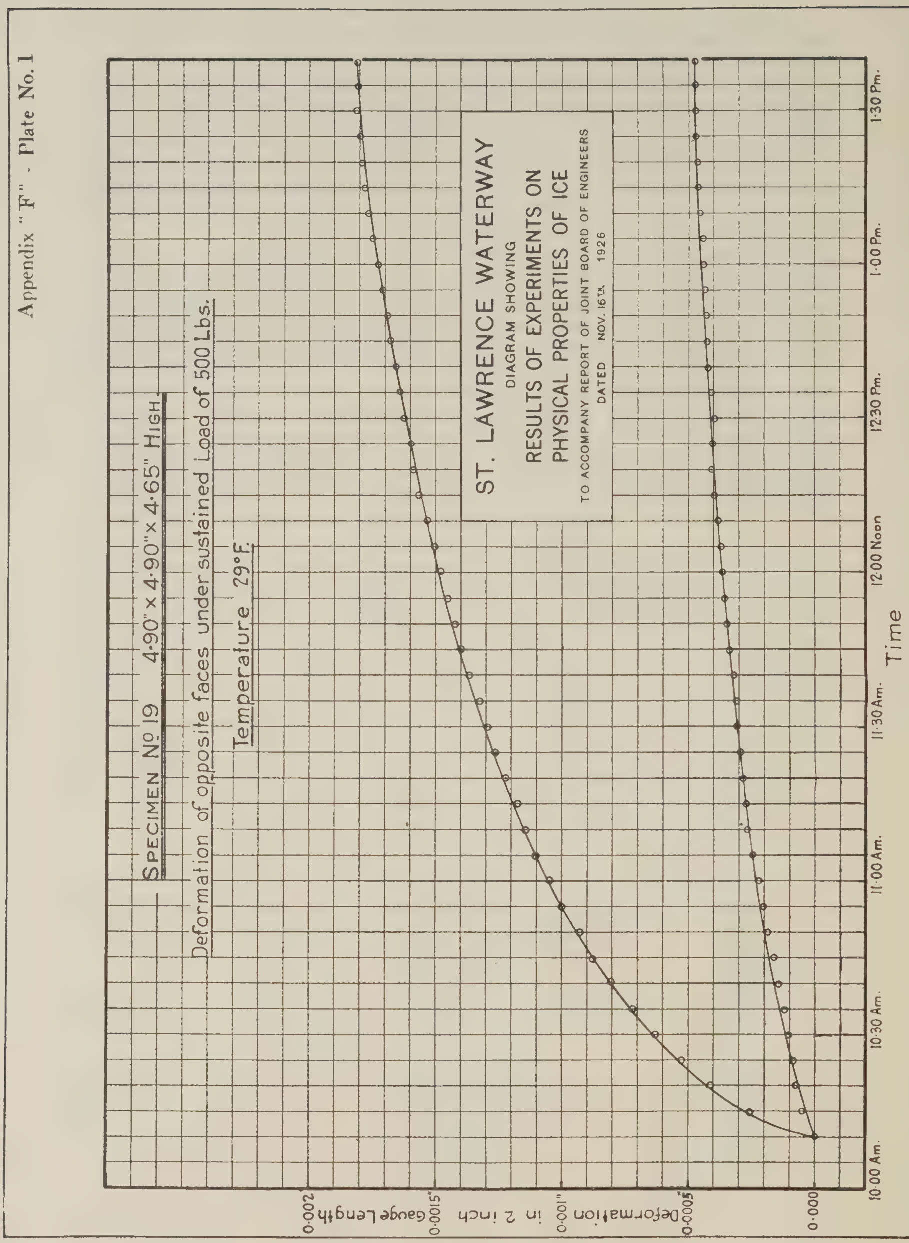
One, with crystals horizontal, had a span of 54.5 inches, and after 20 days had deflected $9\frac{1}{4}$ inches or 17 per cent of the span, resembling a letter "V". The other, with crystals vertical, had a span of $51\frac{1}{2}$ inches, and deflected only 1 inch, or about 2 per cent of the span in the same period.

Another beam of the same dimensions with crystals horizontal, was set so as to project 40 inches as a horizontal cantilever and allowed to deflect under its own weight. The vertical deflection at the free end after 16 days was $13\frac{5}{8}$ inches, or 34 per cent of the cantilever length.

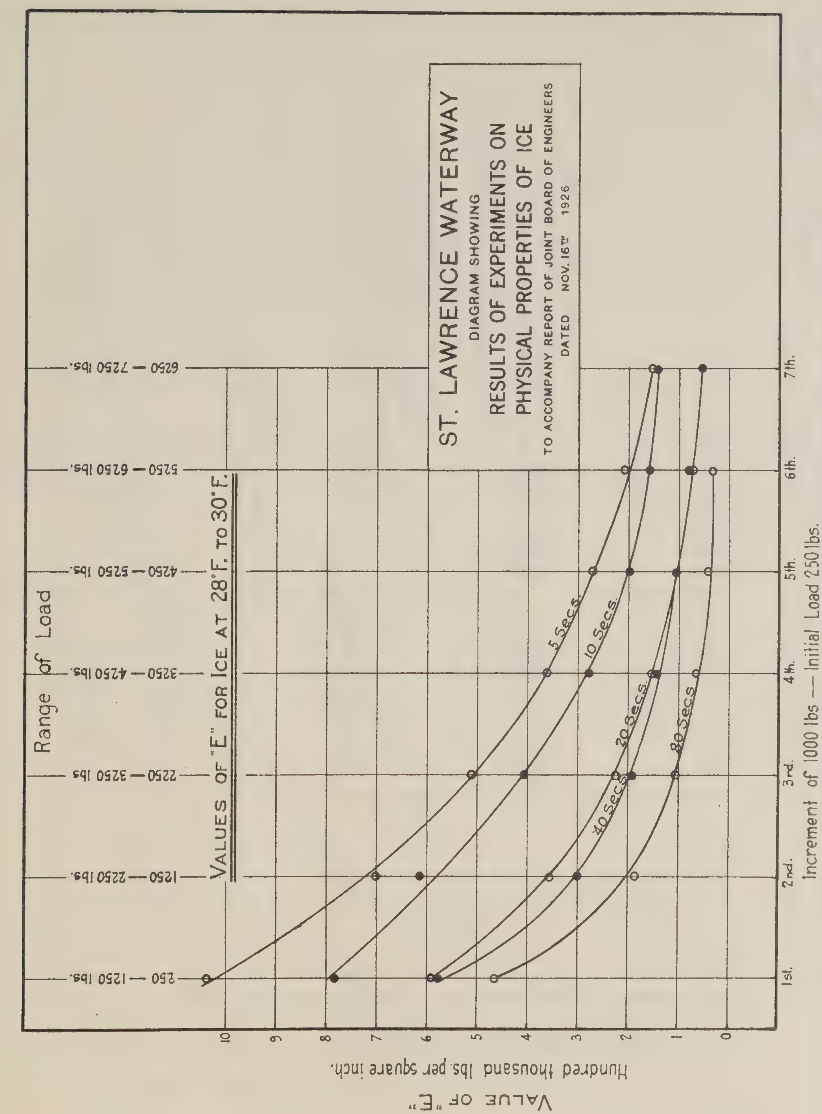
The room temperature was from 28° F. to 30° F., during these tests, and the results show clearly the plastic nature of ice under small loads at this temperature.

Acknowledgments. Thanks are due to the Harbour Commissioners of Montreal for allowing the use of suitable rooms at the Cold Storage Warehouse, and to the staff at the warehouse who were directly concerned in the control of room temperatures. The author of this report, under whose direction the tests were carried out, wishes to pay special tribute to the invaluable assistance received from Mr. E. D. McIntosh, of the Department of Railways and Canals, and the members of his staff engaged in the preparation and testing of specimens. It is largely due to Mr. McIntosh's enthusiasm and skill in supervising the testing, that so much work was accomplished in the time available for the tests.

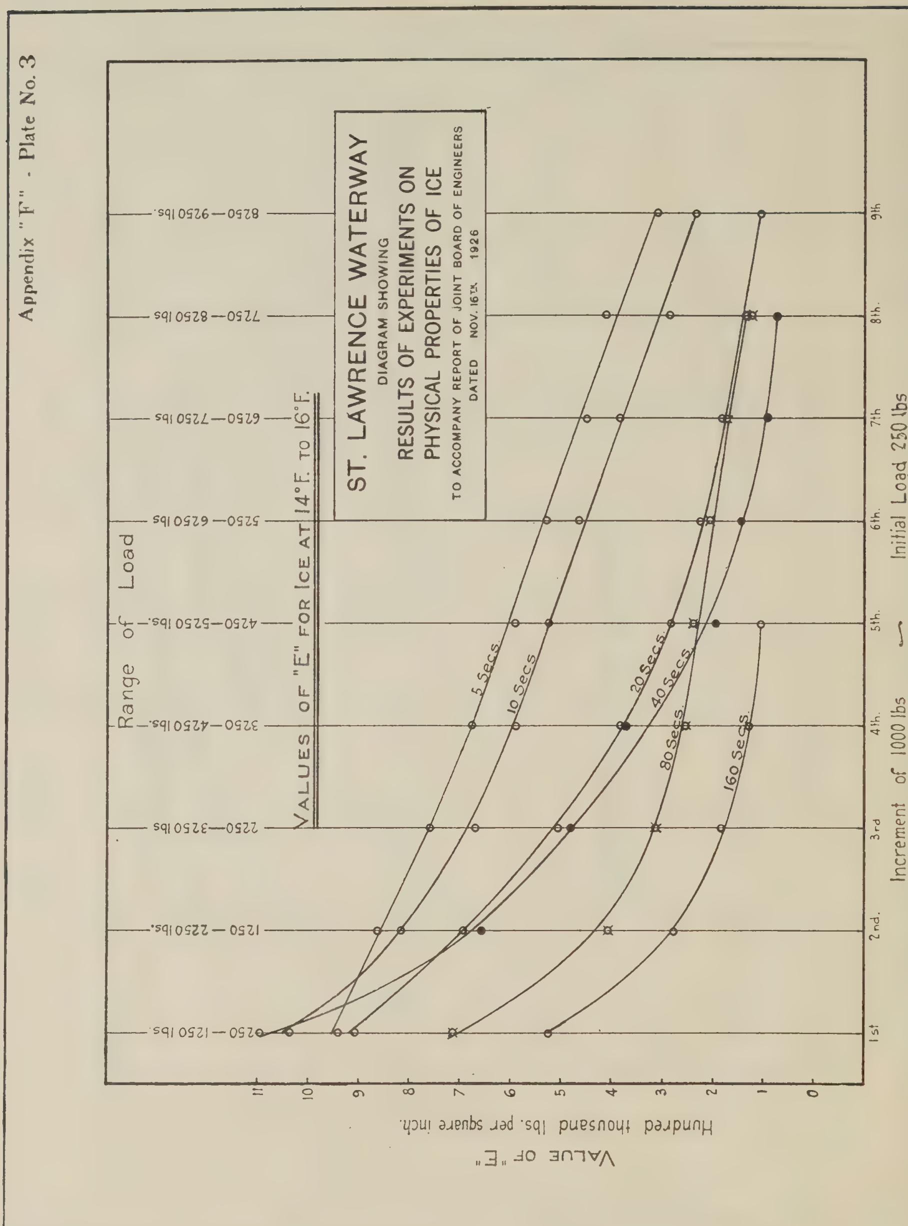
(Sgd.) E. Brown.


Appendix "F" . Plate No. 1
SPECIMEN No 19 4·90" × 4·90" × 4·65" HIGH.
Deformation of opposite faces under sustained Load of 500 Lbs.
Temperature 29°F.
ST. LAWRENCE WATERWAY
DIAGRAM SHOWING
RESULTS OF EXPERIMENTS ON
PHYSICAL PROPERTIES OF ICE
TO ACCOMPANY REPORT OF JOINT BOARD OF ENGINEERS
DATED NOV. 16th 1926
10:00 Am.
10:30 Am.
11:00 Am.
11:30 Am.
12:00 Noon
12:30 Pm.
1:00 Pm.
1:30 Pm.
Time
0·000
0·0005"
0·001"
0·0015"
0·002
Deformation in 2 inch Gauge Length

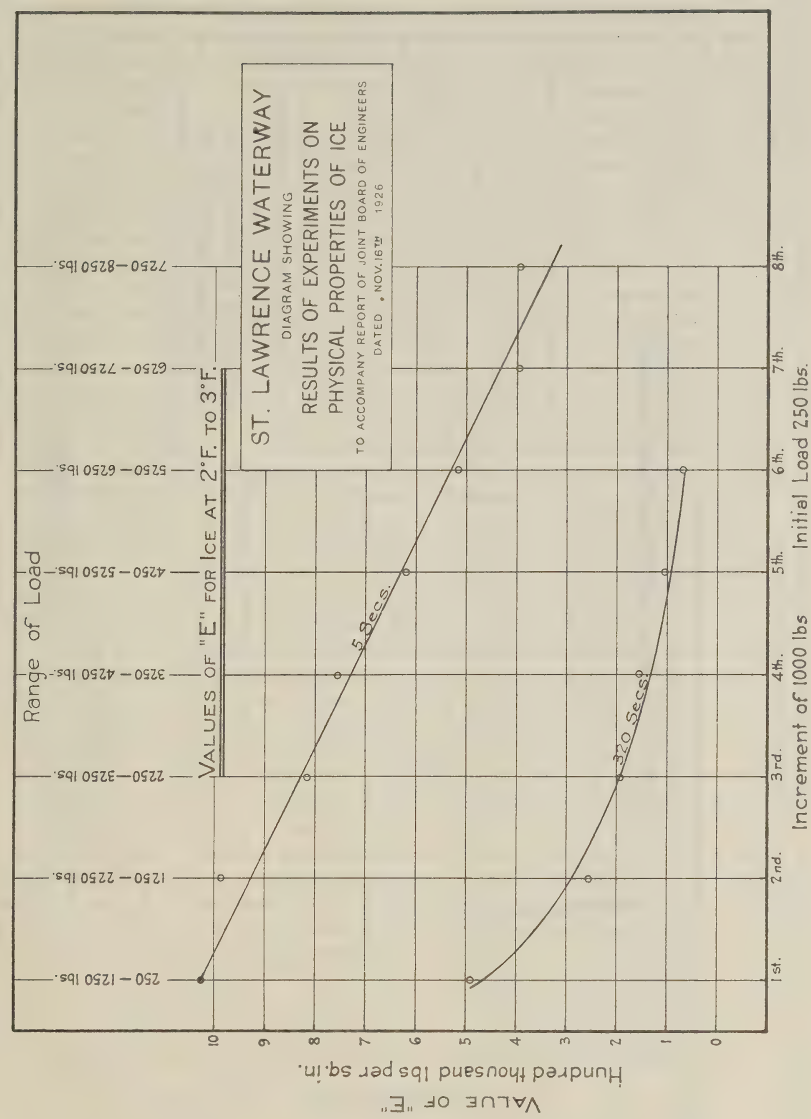
Appendix "F" - Plate No. 2



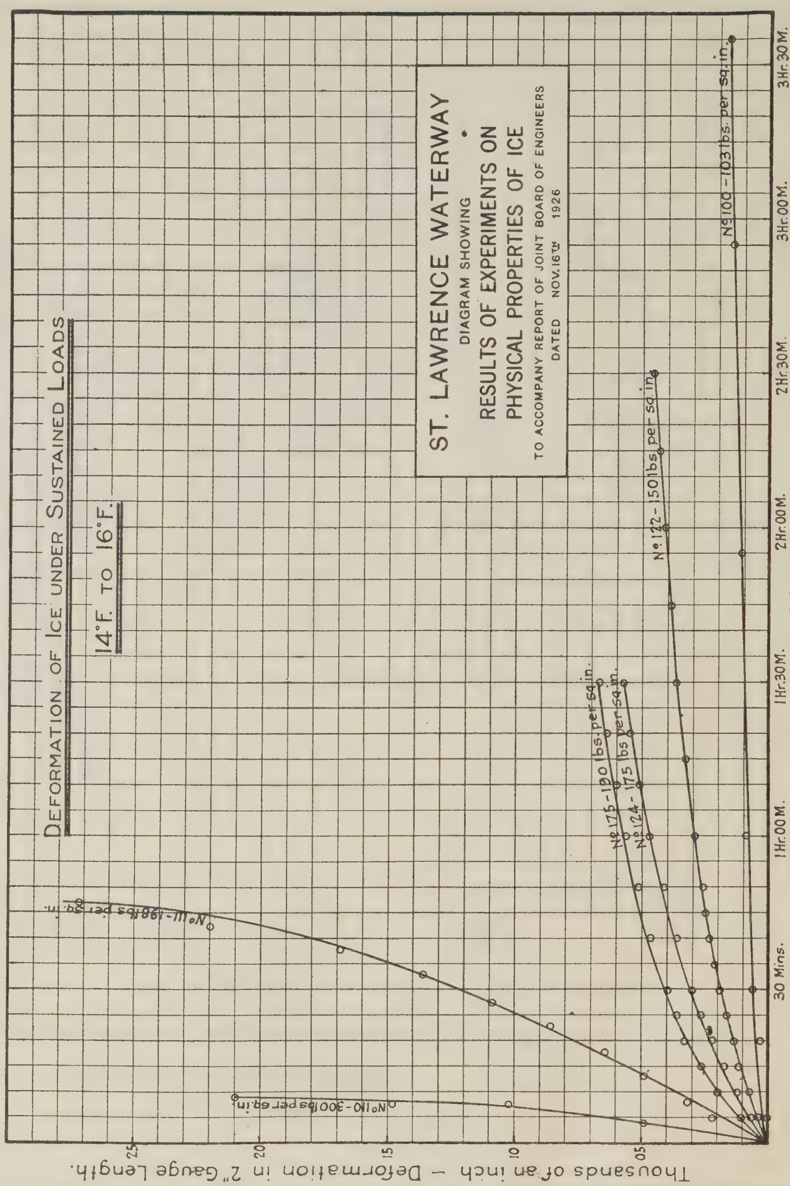
Appendix "F" - Plate No. 3

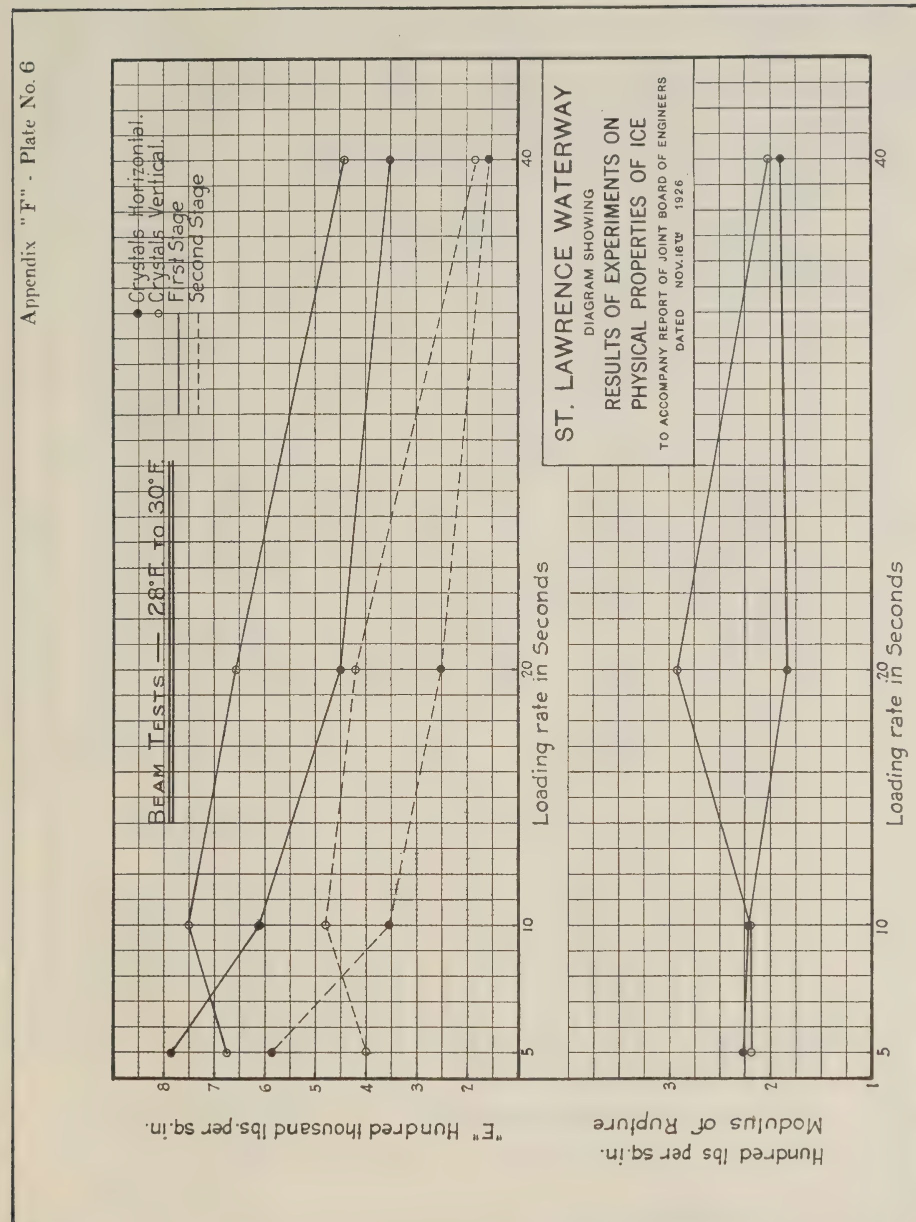


Appendix "F" - Plate No. 4

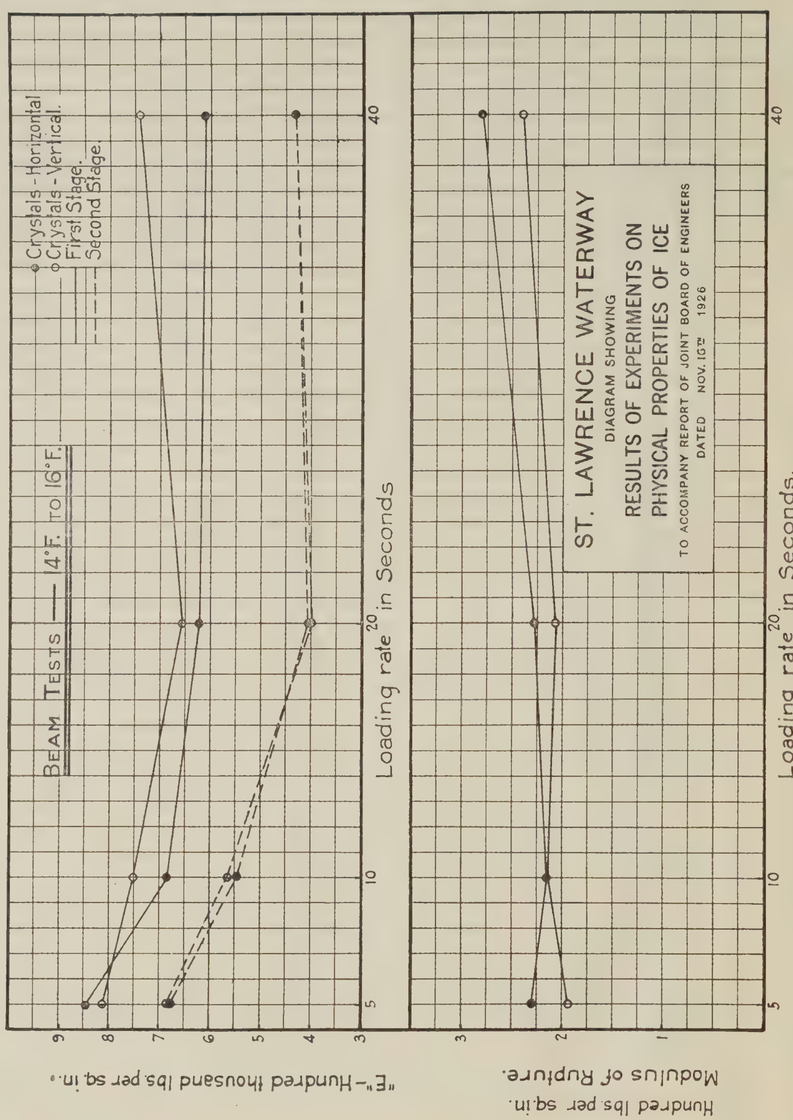


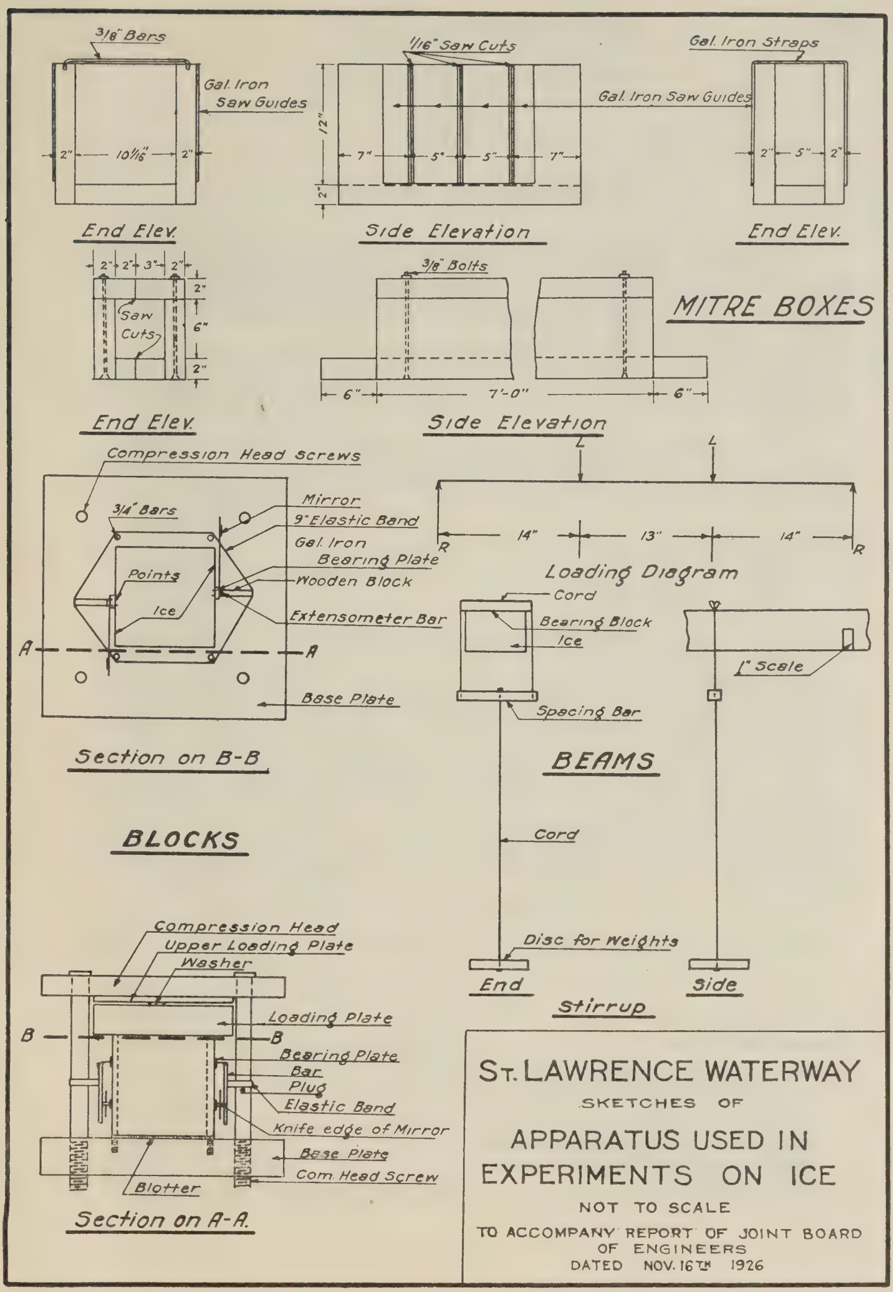
Appendix "F" - Plate No. 5




Appendix "F" - Plate No. 6
BEAM TESTS — 28°F. TO 30°F.
Crystals Horizontal.
Crystals Vertical.
First Stage
Second Stage
ST. LAWRENCE WATERWAY
DIAGRAM SHOWING
RESULTS OF EXPERIMENTS ON
PHYSICAL PROPERTIES OF ICE
TO ACCOMPANY REPORT OF JOINT BOARD OF ENGINEERS
DATED NOV. 16th 1926
"E" Hundred thousand lbs. per sq. in.
Loading rate in Seconds
Modulus of Rupture
Hundred lbs per sq. in.
Loading rate in Seconds

Appendix "F" - Plate No. 7





Appendix "F". Plate No. 8

APPENDIX G

CONSTRUCTION PROGRAM

1. The works required for the improvement of the St. Lawrence are divided into five sections. The works proposed in each section are independent of those proposed in other sections, but the program of construction has been prepared on the basis that through navigation be completed in all sections seven years after the beginning of the works.

2. The time required to complete the through navigation project is largely dependent upon the works in the International Rapids Section, as there the expenditure is larger than in other sections and the works are more difficult to execute.

3. The opening of the St. Lawrence to through deep-draught navigation, with the power works initially connected therewith, under the various plans presented by the Board, will require, in round figures, the following:—

	Cubic yards
Concrete	7,000,000
Earth excavation, dry	80,000,000
Earth excavation, dredging ......40,000,000 to	50,000,000
Rock excavation, dry	12,000,000
Rock excavation, subaqueous	2,300,000

The execution of this work will require the acquisition of considerable new plant which will have relatively little value after the completion of the work. As a consequence, the value of the plant used must be absorbed in the cost of the work. This, along with interest accumulations during the progress of the work, indicates that maximum economy will be secured by choosing a construction period of about seven years for the heaviest part of the work.

4. A detailed construction program, based on these premises, follows. This program is intended to show a sequence of operations by which the work can be executed in seven years, but it is not designed to circumscribe the operations of the engineers in charge of the actual construction. The program is based on completion in seven years after actual construction is begun, with the understanding that unforeseen conditions may force an extension of the time.

CONSTRUCTION SCHEDULE

Item	Year						
	1	2	3	4	5	6	7
Thousand Island Section	......	......	......	......	x	x	x
International Power Section—Scheme 1-242—							
Dam and power houses at foot of Barnhart Island—							
Construction railroads, camps, construction plant, etc.	x	x	......	......	......	......	......
Excavation power houses	......	x	......	......	......	......	......
Concreting power houses	......	......	x	x	x	x	x
Superstructures and installations machinery	......	......	......	......	x	x	x
Construction of dam, to closure	......	x	x	x	x	x	......
Closure of dam and raising pool	......	......	......	......	......	......	x
Tail-race excavation	......	......	x	x	x	x	x

CONSTRUCTION SCHEDULE—*Continued*

Item	Year						
	1	2	3	4	5	6	7
Innternational Power Section—*Con.*							
Navigation Works—							
Approach channel above Robinson Bay lock	......	......	......	x	x	x	......
Robinson Bay lock	......	x	x	x	x	......	......
Canal prism, Robinson Bay lock to Grass River lock	......	......	x	x	x	......	......
Grass River lock and wasteway	......	......	......	x	x	x	x
Approach channel, Grass River lock to river	......	......	......	......	......	......	x
Dike at Grass River lock	......	......	......	......	......	x	x
Diversion dike and flood channel, mouth of Grass River	......	......	......	......	......	x	x
Diversion—Ottawa Branch, New York Central Railroad	......	......	......	......	......	x	x
Dredging, south Cornwall Island channel	......	......	x	x	x	x	x
Excavation, north Cornwall Island channel	x	x	......	......	......	......	......
Road relocation for canal	x	......	......	......	......	......	......
Dykes and drainage ditches	x	x	x	x	x	x	......
Protection Iroquois	......	......	......	......	x	x	......
Protection Morrisburg	......	......	......	......	x	x	......
Fourteen-foot lock at Bergen Lake	......	......	x	......	......	......	......
Control works, head of Massena power canal	......	......	......	......	x	x	......
Initial channel excavation—							
At Chimney Point	......	......	......	......	x	x	x
Above Galop Island	x	x	......	......	......	......	......
Cut through Island	x	x	x	x	......	......	......
Channel below cut	x	x	x	x	x	......	......
Channel below Lalone-Lotus Islands	......	......	......	......	x	x	......
Sparrowhawk Point to Ogden Island	......	......	x	x	x	x	x
Control works at Galop	......	......	x	x	x	......	......
Railroad relocation	......	......	......	......	x	x	......
Highway relocation	......	......	......	x	x	x	......
Clearing pool	......	......	......	......	......	x	......
Ogden Island Project No. 4–224—							
Channel enlargement north of Galop Island	x	x	......	......	......	......	......
Dam in channel north of Galop Island	......	x	......	......	......	......	......
Excavation at Chimney Point	......	x	x	x	......	......	......
Cofferdams, south Galop channel	......	......	x	......	......	......	......
Excavation of south Galop channel	......	......	x	x	......	......	......
Removal of cofferdams	......	......	......	......	x	......	......
Excavation, Sparrowhawk Point to Ogden Island	......	......	x	x	......	......	......
Diversion at Ogden Island and channel south of Ogden Island	x	x	......	......	......	......	......
Dam in diversion at Ogden Island	......	x	......	......	......	......	......
Lock at Ogden Island	x	x	......	......	......	......	......
Power house south of Ogden Island	x	x	......	......	......	......	......
Cofferdam north of Ogden Island	......	x	......	......	......	......	......
Power house substructure north of Ogden Island	......	......	x	x	x	......	......
Diversion through Long Sault Island	x	x	x	......	......	......	......
Dam in south Sault channel	......	x	......	......	......	......	......
Dam at head of Barnhart Island	......	......	......	x	x	x	......
Power houses at foot of Barnhart Island	......	......	......	x	x	x	x
Excavation at foot of Barnhart Island	......	......	......	x	x	x	x
Excavation of Grass River lock	......	x	x	......	......	......	......
Concrete in Grass River lock	......	......	......	x	x	......	......
Excavation of channel, Robinson Bay lock to Grass River	......	......	......	x	x	......	......
Concrete in Robinson Bay lock and guard gates	......	......	......	......	......	x	x
Excavation of channel above Robinson Bay lcok	......	......	......	......	x	x	x
Excavation north and south of Cornwall Island	......	......	......	x	x	x	x
Lock for 14-foot navigation, Canadian mainland	......	......	......	......	......	x	......
Diversion of Ottawa and New York Railroad	......	......	......	......	x	x	......
Dykes and drainage ditches, Morrisburg to Barnhart Island	......	......	......	x	x	x	......
New Massena Canal intake	......	......	......	x	x	......	......
Dykes, United States side	......	......	......	......	......	x	x
Chrysler Island Project No. 5–217—							
Channel enlargement at Chimney Point	......	x	x	x	......	......	......
Channel enlargement north of Galop Island	x	x	......	......	......	......	......

CONSTRUCTION SCHEDULE—*Continued*

Item	Year						
	1	2	3	4	5	6	7
Chrysler Island Project No. 5-217—*Con.*							
Dam in channel north of Galop Island		x					
Cofferdams above and below channel south of Galop Island			x				
Excavation of material in south Galop channel			x	x			
Removal of cofferdams					x		
Enlargement of channels, Sparrowhawk Point to Morrisburg			x	x			
Cofferdams at sites of United States and Canadian power houses Chrysler Island	x	x					
Construction of power houses at Crysler Island		x	x	x			
Lock for 14-foot navigation and part of dam at Chrysler Island	x	x					
North 2,200 feet of dam at Crysler Island			x	x			
Excavation of sites for lock opposite Weavers Point	x						
Construction of above lock		x	x				
Excavation of material in channel above and below lock opposite Weavers Point			x	x			
Diversion of Grand Trunk Railway and building of dykes, Iroquois to Crysler Island			x	x			
Excavation of head-race North, Crysler Island power house			x	x		x	
Excavation of tail-race rock, Crysler Island power house				x	x		
Diversion through Long Sault Island	x	x	x				
Dam in south Sault channel		x					
Dam at head of Barnhart Island				x	x	x	
Power houses at foot of Barnhart Island				x	x	x	x
Excavation at foot of Barnhart Island				x	x	x	x
Excavation of Grass River lock		x	x				
Concrete in Grass River lock				x	x		
Excavation of channel, Robinson Bay lock to Grass River				x	x		
Concrete in Robinson Bay lock and guard gates						x	x
Excavation of channel above Robinson Bay lock					x	x	x
Excavation north and south of Cornwall Island				x	x	x	x
Lock for 14-foot navigation, Canadian mainland						x	
Diversion of Ottawa and New Railroad					x	x	
Dykes and drainage ditches, Morrisburg to Barnhart Island				x	x	x	
New Massena Canal intake				x	x		
Dykes, United States side						x	x
Lake St. Francis Section					x	x	x
Soulanges Section—Ile aux Vaches Project—1st Stage—							
Diversion of Riviere Delisle west of Coteau Junction	x						
Excavation of site of Coteau du Lac lock	x						
Construction of lock at Coteau du Lac		x					
Construction of side canal, Coteau Landing to Coteau du Lac, with breakwater at Coteau Landing		x	x				
Construction of lock at Cascades Point	x	x					
Construction of lock at Chamberry Gully			x	x			
Removal of materials required for side canal, Chamberry lock to Cascades lock, and construction of dyke adjacent		x	x				
Removal of material in side canal, Cedars to Chamberry Gully lock			x	x	x		
Construction of syphon culverts east of Provincial power house, with channels between Soulanges Canal and river		x	x				
Construction of control works at Clark Island and excavation of diversion channels, Clark Island to Broad Island; relocation and reconstruction of Canadian National Railway on Clark Island and Grand Ile			x	x	x	x	
Excavation of diversion channels east end of Grand Ile	x	x					
Construction of dam and substructures of power house, Ile Juillet to Ile aux Vaches	x	x	x				
Construction of dam, Ile aux Vaches to Cedars, with substructures of power houses				x	x	x	

CONSTRUCTION SCHEDULE—*Concluded*

Item	Year 1	2	3	4	5	6	7
Soulanges Section—*Con.*							
Construction of dam, Grande Ile to Ile Juillet	......	......	......	......	......	x	x
Construction of dykes, Coteau du Lac to Cedars, dykes on Grande Ile	......	x	x	x	x	......	......
Deepening of Soulanges Canal and closing of the present outlets of Delisle, Rouge, and A la Graisse Rivers	......	......	......	......	......	x	x
Completion of entrance channels at the head and foot of the Section and enlargement of Coteau Rapids at Round Island	......	......	......	......	x	x	x
Lachine Section—							
Removal of material in submarine channel, deep water Lake St. Louis to old lock No. 5, Lachine	......	......	......	x	x	x	x
Construction of syphon culverts at head of the aqueduct of the City of Montreal	......	x	x	......	......	......	......
Excavation of sites for locks at Montreal, Nuns Island	......	x	x	......	......	......	......
Construction of locks at Montreal and Verdun	......	......	x	x	x	......	......
Construction of new intakes for Verdun and The Montreal Water and Power Co	......	x	x	......	......	......	......
Construction of timber-crib walls above and below Canadian Pacific Railway, New Highlands	......	......	x	x	......	......	......
Excavation of material in overland canal, Lachine to Verdun	......	......	x	x	x	x	......
Excavation of site of Verdun lock and preparation of foundation for dykes, Verdun to Nuns Island	......	......	......	x	......	......	......
Construction of lock at Verdun and guard gates above	......	......	......	......	x	x	x
Construction of dykes, Verdun to Nuns Island	......	......	......	......	x	x	......
Removal of material in prism, Verdun to Nuns Island	......	......	......	......	x	x	......
Construction of culverts under Canadian National Railway embankment at Point St. Charles	......	......	x	......	......	......	......
Removal of material in prism, Nuns Island to Montreal lock	......	......	......	x	x	x	......
Construction of walls and dykes, Nuns Island to the lock at Montreal	......	......	......	......	......	x	x
Construction of supply weir and dykes, Nuns Island lock to Verdun shore	......	......	......	......	......	x	x
Construction of dam at Ile au Diable	......	......	......	......	x	x	x
Construction of high level bridges at the Canadian Pacific Railway intersection at Highlands and the Canadian National Railway intersection at Victoria Bridge	......	......	......	......	......	x	x

5. The following remarks explain the foregoing program:—

6. Thousand Islands Section. The plans for this section show material to be removed at about a dozen places. The work to be done at each of these places could be allotted to a separate construction agency, but lower prices will be obtained if the number of such agencies is reduced to one or two, as larger plant will then be utilized and overhead expenses will be proportionately small. In this section the material to be removed is not large and can be done by one dredging outfit in three years. The plant required is not special and would not have to be built for this work. As a consequence, this work need not be commenced until three years before the time chosen for the completion of through navigation.

7. International Rapids Section. As explained in Appendix C, there are a number of proposals for the improvement of the International Rapids Section.

8. In the single-stage project with the main dam and power houses on deep foundations at the foot of Barnhart island, the time required for the construction of these structures determines the time within which the project can be built. The time chosen, however, gives maximum economy for the general excavation work.

9. If the alternative is chosen of placing the main dam at the head of Barnhart island, it will be necessary to construct diversion works before work on the dam is begun, and no substantial saving in time of construction is anticipated.

10. Improvement by Two-stage Projects. With either of the two-stage projects, a diversion at Galop rapids is required to be completed before the channel south of Galop island is unwatered, or work is begun on the improvements shown in that channel. This requires shifting of plant, and concentration of forces on three works, one after the other. Estimates show that the work at Galop rapids can be done with a moderate amount of plant in four or five years. The excavation at Galop island cannot, however, be quite completed without a reference to condition of works at Ogden island, or at Crysler island, as the case may be. The cofferdam at the head of the south Galop channel cannot be removed before the water level below is raised.

11. With project No. 4-224, the dam, power house, and lock at Ogden island can be built without special regard to what is done at Barnhart island, but the completion of all channel enlargement between Lotus island and Ogden island is required before the plant at Ogden island begins to operate. In this project the works at the foot of Barnhart island must be built simultaneously with, or subsequent to, the works at Ogden island. They should not be built before the works at Ogden island, as difficulties would then arise in constructing the upper works, and in dealing with ice conditions.

12. In this project the excavation of a diversion channel through Ogden island is required before the main channel of the river can be cofferdammed and before the construction of the power house at that point can be begun. This involves some shifting of plant, but it will not involve loss of time, as large quantities of excavation have to be done between Lotus island and Ogden island which can be delayed until the diversion channels at Ogden island are completed. The unwatering of the sites of the power house at Ogden island should not prove difficult after the diversion channel is completed, as the solid rock surfaces are not far below the water level at that point.

13. The work at Barnhart island and at the foot of the section in this project are generally the same as in the single-stage project with the dam at the head of Barnhart island, but on a smaller scale, and involve the same construction problems.

14. With the two-stage development, the lock and canal at Ogden island are closely associated with the works to be built in the river and both should be completed at the same time. However, the locks and side canal required for carrying navigation past the lower dam and power house at the foot of the section are not closely associated and the construction of the lock can be delayed. A lock for passing 14-foot navigation is required north of Sheek island in order to connect the water level as it is raised with the present Cornwall canal.

15. Crysler Island Project. With project No. 5-217, a construction program much the same as that above described for project No. 4-224 is required at Galop rapids and at Barnhart island. At Crysler island the works proposed are different from those proposed at Ogden island and a different procedure is required. A lock for passing 1-foot navigation is required in the dam at the outset.

16. The side canal and lock at this point can be built without special reference to the dam and power houses. Some economy is, however, obtained by bringing the lock and side canal into use when the water level in the river is raised above elevation 229. Estimates are prepared on this basis. The elevation of water passages in power houses at Crysler island will permit water to be passed through them after their construction, if desired.

17. Lake St. Francis Section. The execution of the work in this section requires the dredging of 1,584,000 cubic yards. This can be done by one dredge in three years.

18. Soulanges Section. In the Ile aux Vaches project, progress must be well arranged in advance, as the several works are dependent upon one another.

19. To prevent flooding of the lands north of the Ile aux Vaches pool, the water can not be raised above elevation 140 before the present Soulanges canal is utilized as a drainage outlet, and consequently abandoned for navigation. A new waterway must then be ready to pass ships of 14-foot draft at elevation 140. At this stage the canal and enlargement of the river at Coteau rapids and the dam at Cedars must be practically completed. The side canal from Cedars to the Ottawa arm of lake St. Louis must be ready to hold water at elevation 140.

20. At the beginning of the winter chosen for the transfer of 14-foot navigation from the present Soulanges canal to the new canal, arrangements must be made for the closing of the Soulanges canal above Coteau du Lac and the joining of this canal with the syphon culverts just east of the Provincial power house. This must be followed by the lowering of the water level in the Soulanges canal and the deepening of that canal to the extent of about 9 feet. This is to be done to enable the old canal to carry the spring discharge of the Delisle, Rouge and A la Graisse river.

21. During the open-water period after the Cedars reach is raised to elevation 140, the various works will have to be put in shape for a higher level, as winter conditions will require a rise to about 148 in order to operate with safety. This will require the completion of works at Cedars eight months after the Soulanges canal begins to act as a drainage canal.

22. Lachine Section. The project for the Lachine section can be built without interfering with the power development and without interfering with 1-foot navigation.

23. The works proposed in this section can be separated into many parts, each of which can be built and completed without regard to others. Before the works between Nuns island and Victoria bridge can be completed, it is necessary to build culverts at the north end of Victoria bridge to care for drainage. It is also necessary to change the intake works of the Montreal Water and Power Co. and those of the city of Verdun from the river to the Montreal aqueduct.

24. Before the 25-foot canal for improved navigation can be built across the aqueduct of the city of Montreal, it will be necessary to divert the flow at the point and to construct syphon culverts under the new canal.

25. In the project presented, a dam is to be built across the river at Ile au Diable. This can be constructed by ordinary methods, as the solid rock at that point is close to the present water surface and the river is not deep.

26. The work in the Lachine section can be economically done in about six years.

Adopted by Board July 13, 1927.